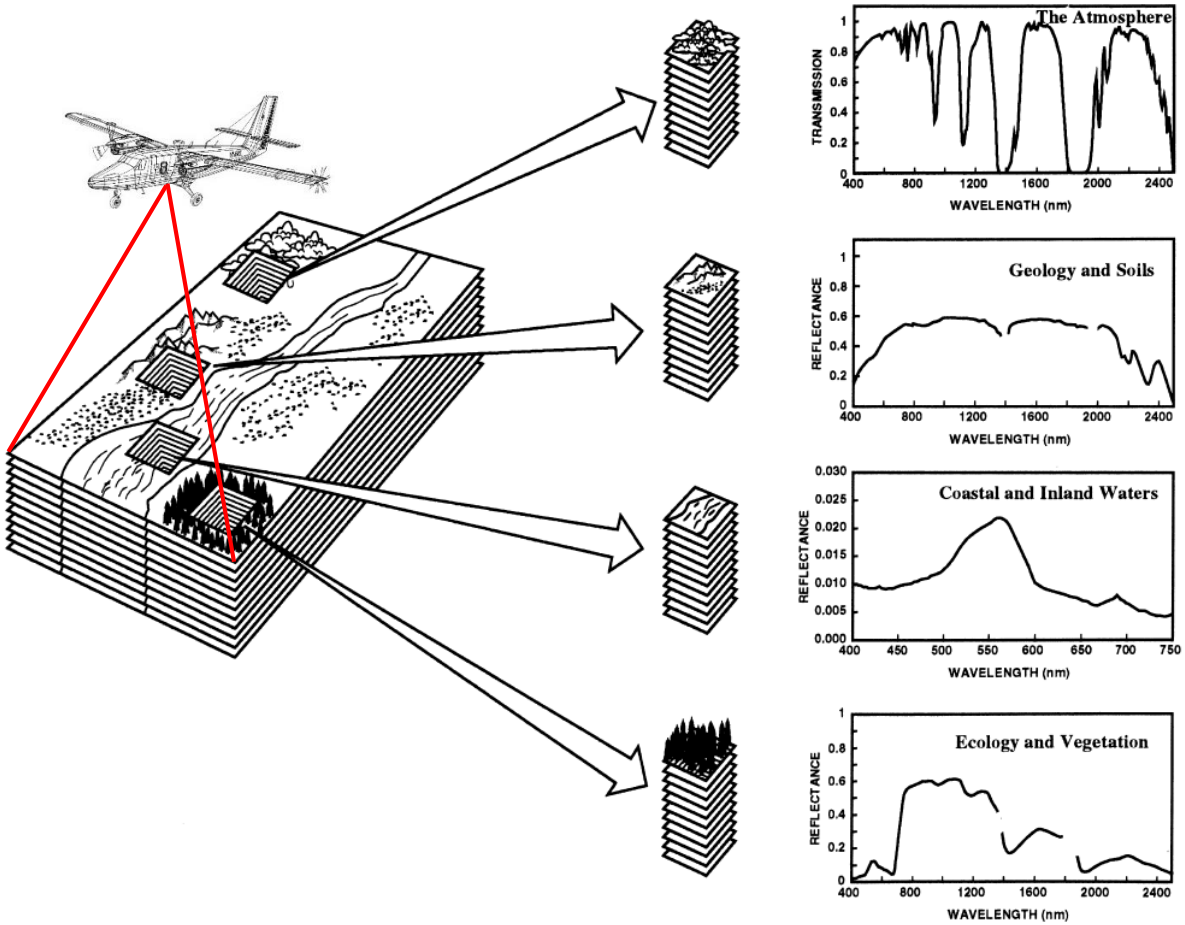
Airborne retrievals of methane, carbon dioxide, and water vapor concentrations at high spatial resolution: application to AVIRIS-NG

Thorpe, A. K.[1], Frankenberg, C.[1,2], Thompson, D. R.[1], Duren, R.M.[1], Aubrey, A. D. [1], Bue, B. D.[1], Green, R. O.[1], Gerilowski, K.[3,] Krings, T.[3], Borchardt, J.[3], Kort, E. A.[4], Colm Sweeney[5], Conley, S.[6,7], Roberts, D.A.[8], Dennison, P.E.[9]

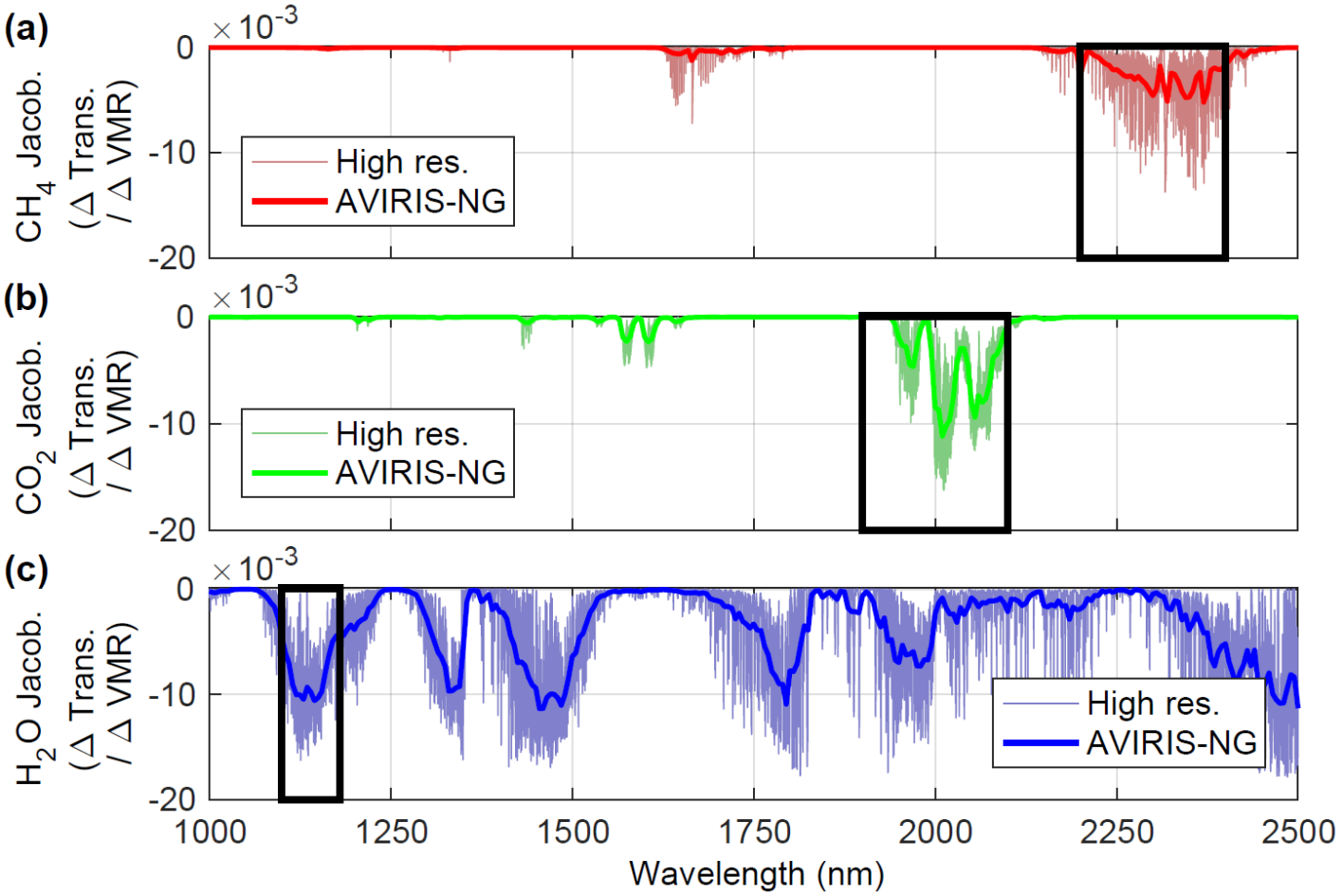
[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States
[2] California Institute of Technology, Pasadena, California, United States
[3] Institute of Environmental Physics (IUP), University of Bremen, Bremen, Germany
[4] University of Michigan, Ann Arbor, United States
[5] Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, United States
[6] Global Monitoring Division, NOAA Earth System Research Laboratory, Boulder, Colorado, United States
[7] Scientific Aviation, 3335 Airport Road, Boulder, CO, United States
[8] University of California, Santa Barbara, Santa Barbara, California, United States
[9] University of Utah, Salt Lake City, Utah, United States

- Next generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG)
  - Pushbroom sensor
  - 36° field of view
  - 380 to 2,510 nm
  - 5 nm spectral resolution
  - 427 spectral channels



Gas absorption features

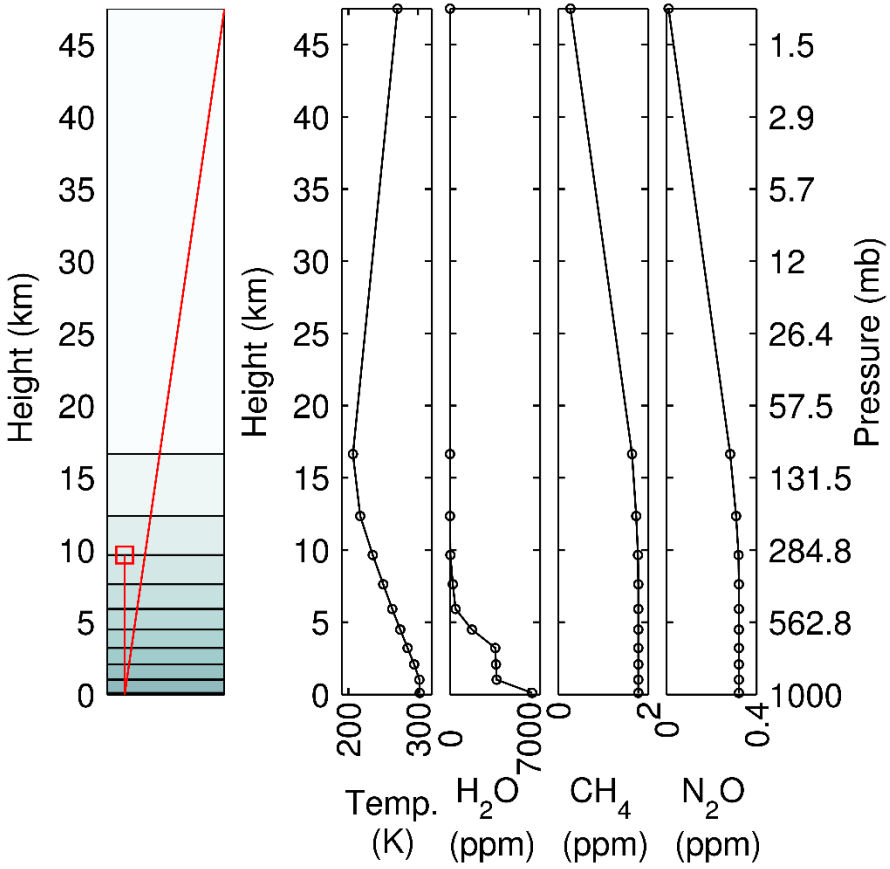
- CH_4, CO_2, and H_2O absorption features



Gas retrievals

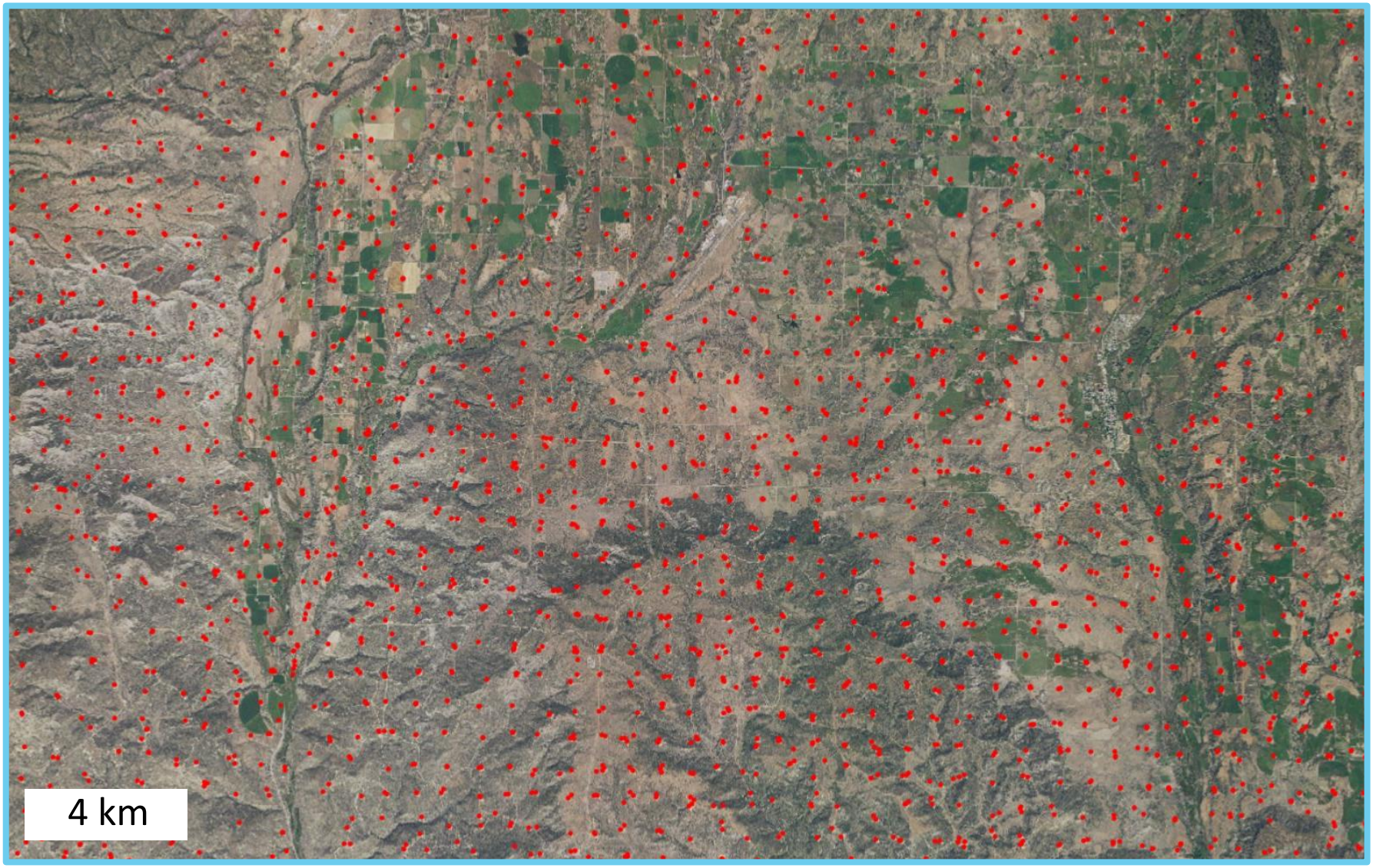
- Iterative maximum a posteriori-DOAS algorithm (Frankenberg et al., 2005)
  - Adjusts vertical column densities of multiple gasses until total optical density fits the observed measurement

CH_4 retrieval (Thorpe et al., 2014):

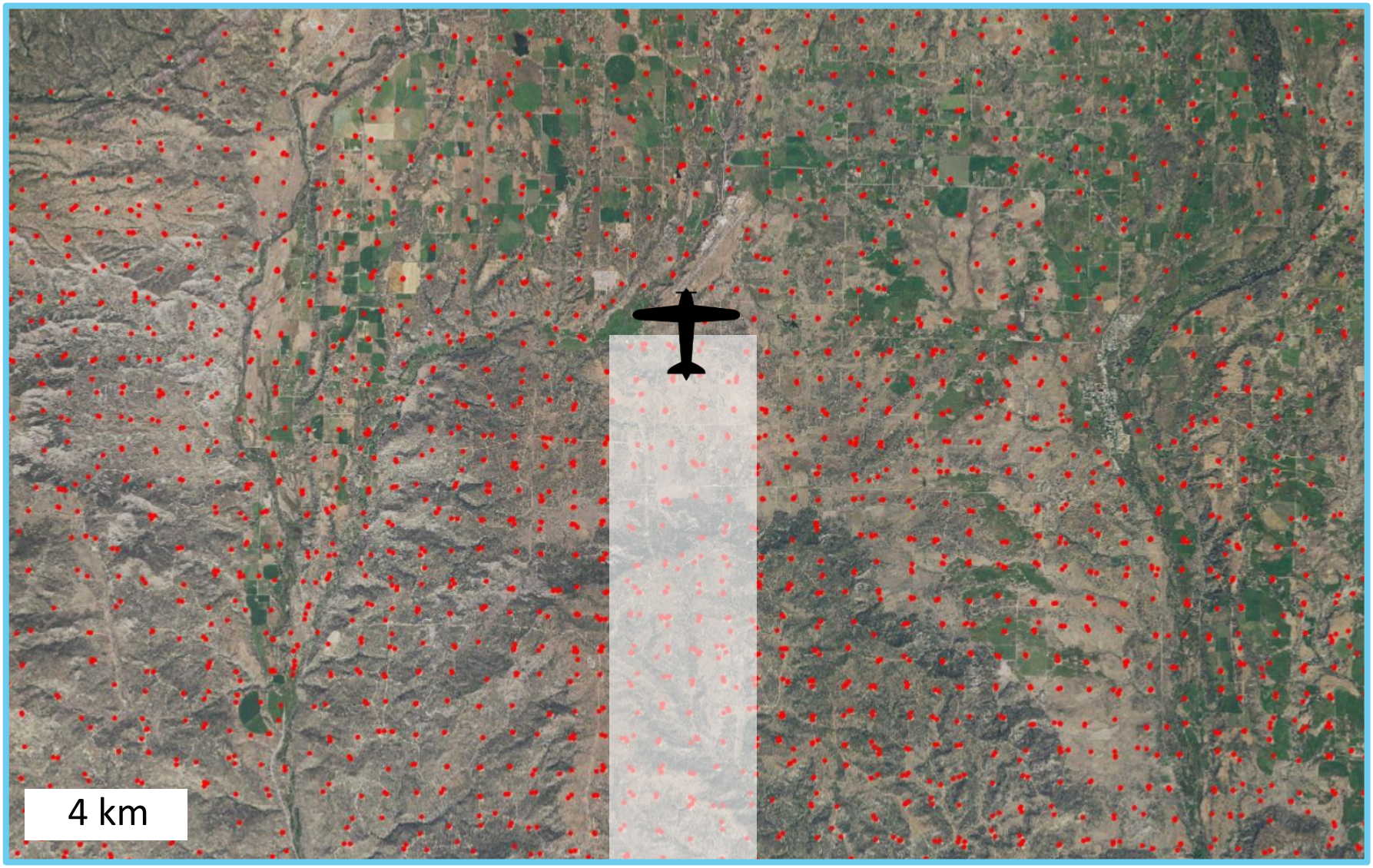


32 x 22 km , 704 km^2 region:

32 x 22 km , 704 km^2 region:



32 x 22 km , 704 km^2 region:

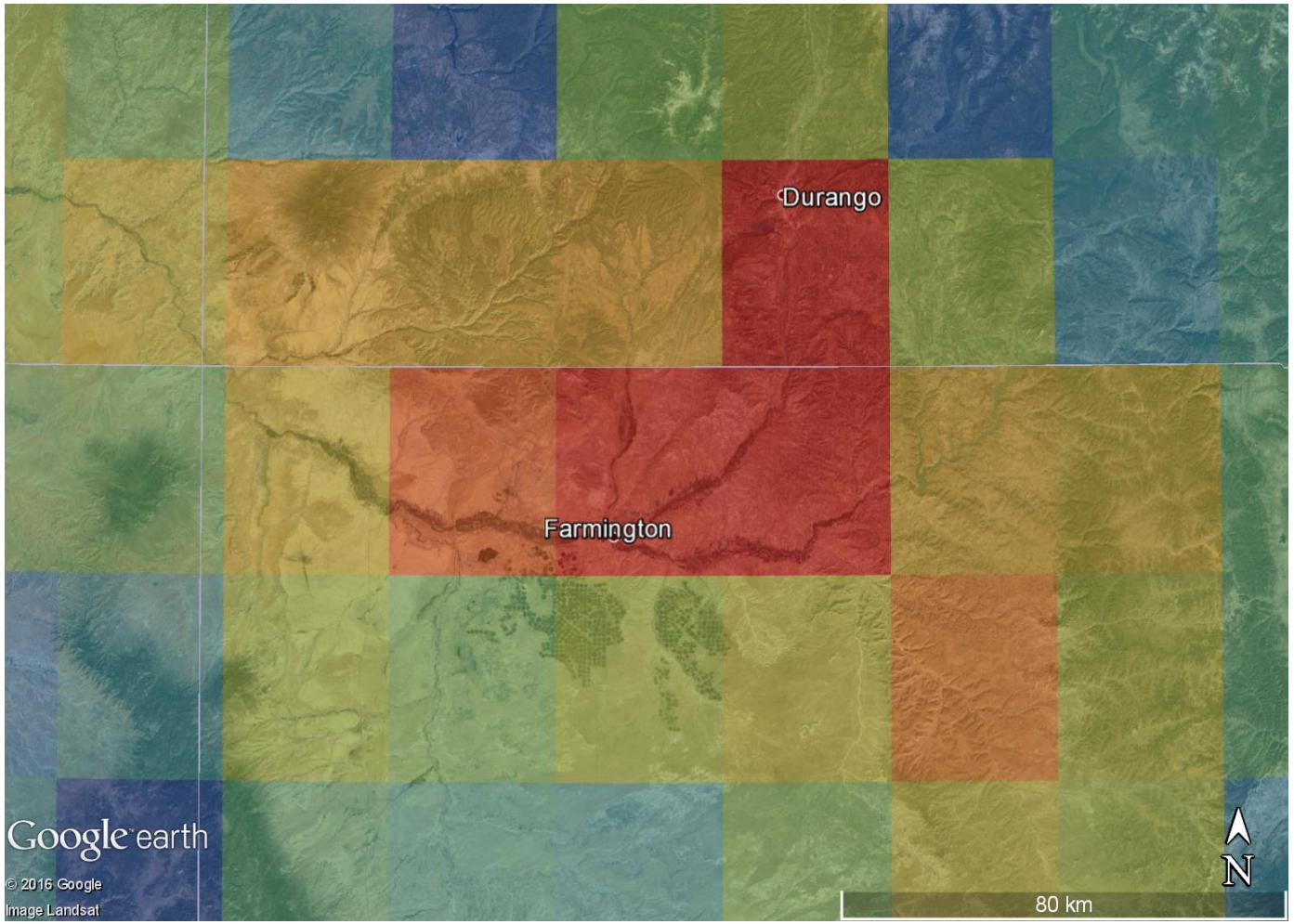


Study site

- San Juan Basin (Four Corner: Colorado, New Mexico)
  - Coal bed CH_4
  - 20,000 oil and gas wells

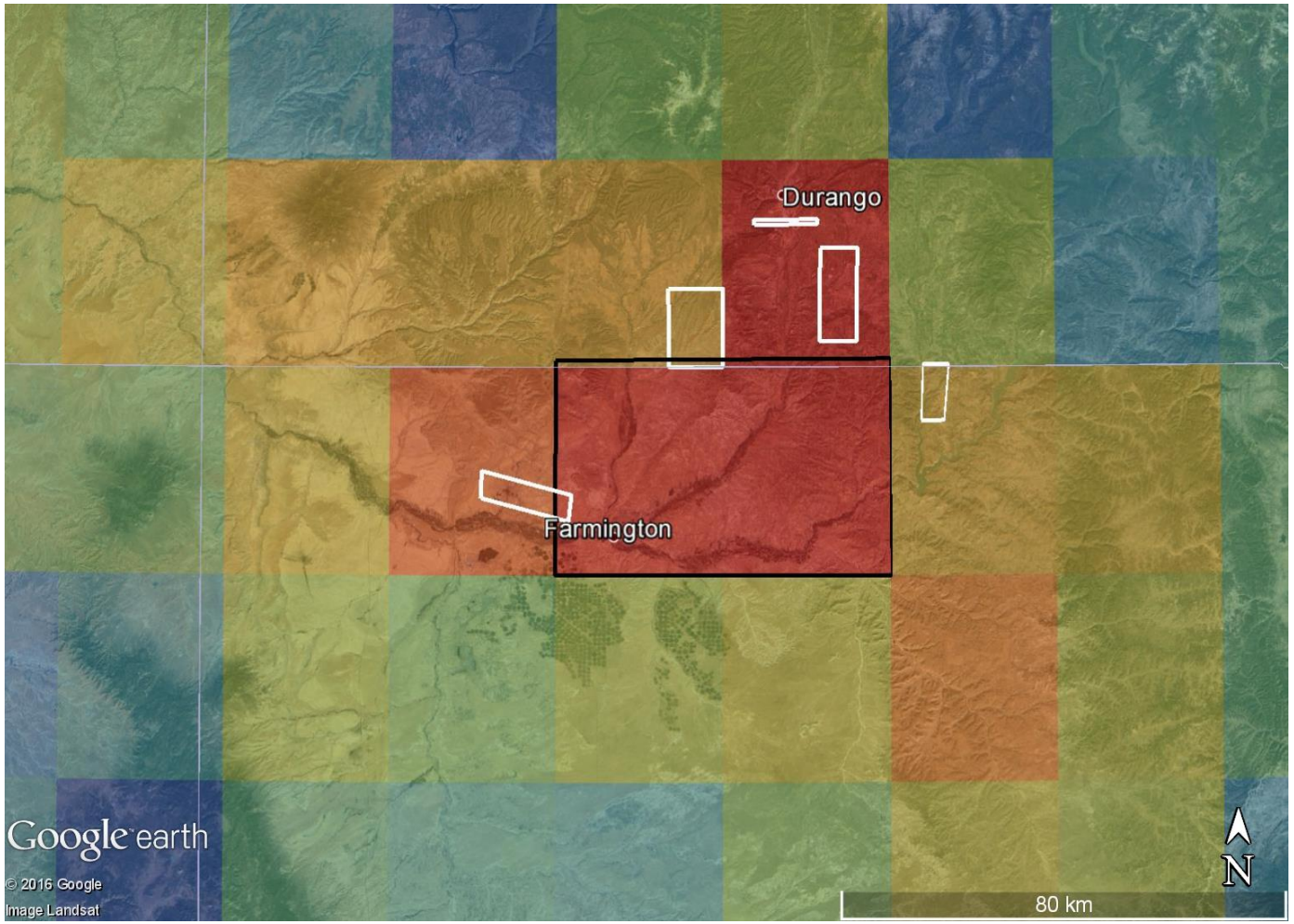
Study site

- CH_4 enhancement observed with SCIAMACHY satellite (Kort et al., 2015)



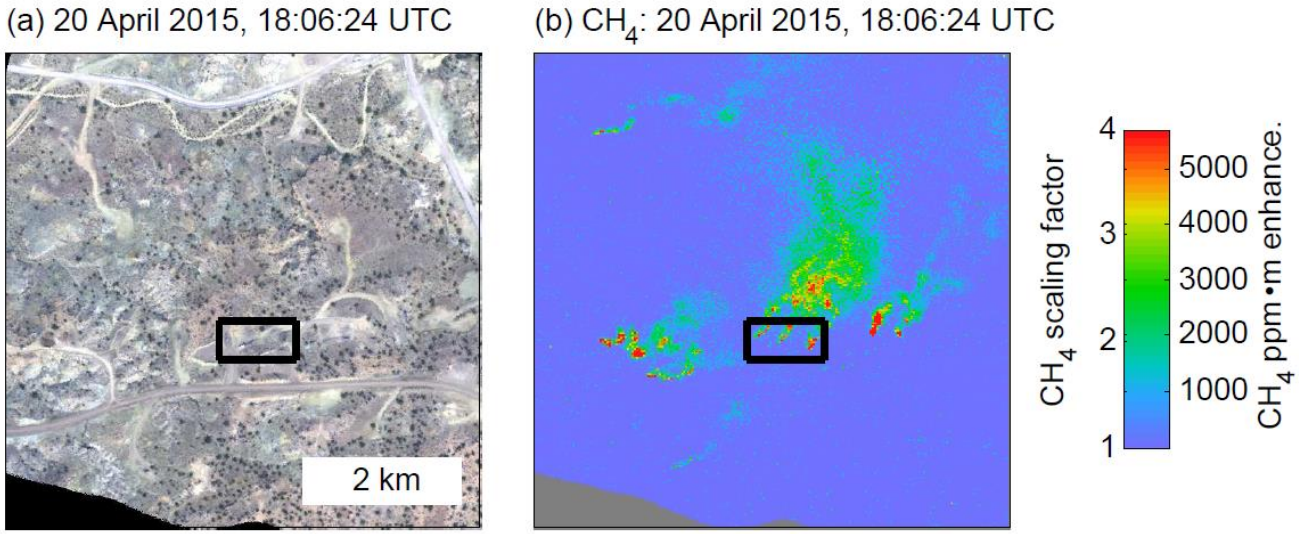
Study site

- AVIRIS-NG flight boxes target SCIAMACHY hotspot
  - Black: Survey (3 km above ground level, 3 m pixels)
  - White: Directed study (1 km above ground level, 1 m pixels)



Results (CH_4)

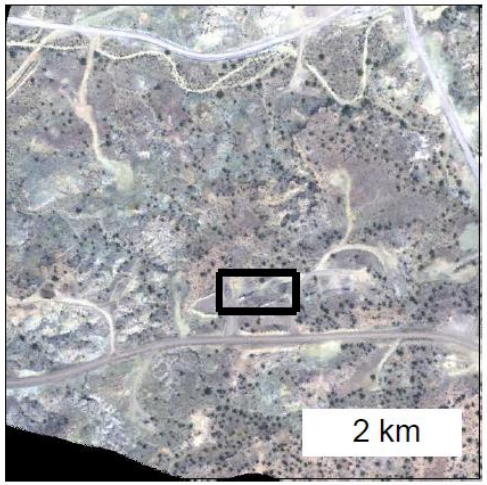
- Example 1: Coal mine ventilation shaft emissions



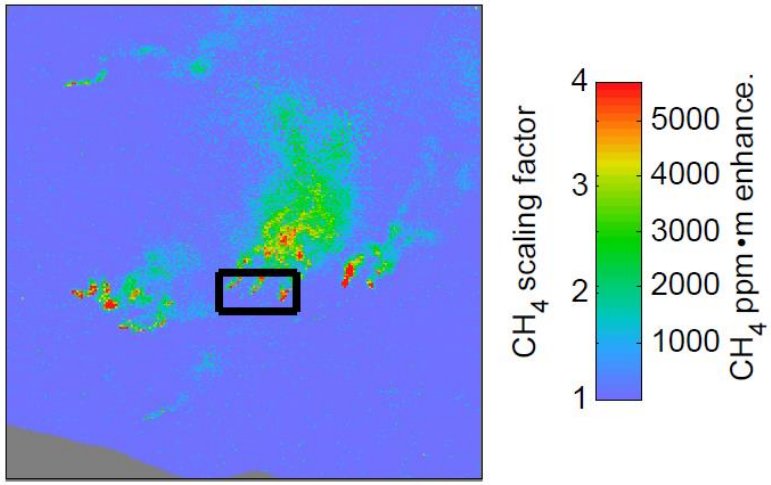
Results (CH_4)

- Example 1: Coal mine ventilation shaft emissions

(a) 20 April 2015, 18:06:24 UTC



(b) CH_4: 20 April 2015, 18:06:24 UTC



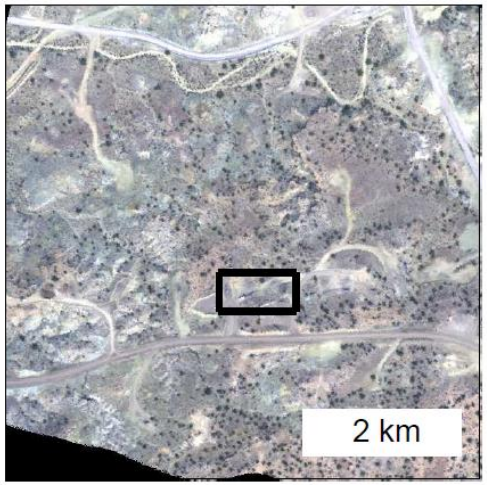
(c) 20 April 2015, 18:06:24 UTC

(d) Google Earth: 15 March 2015

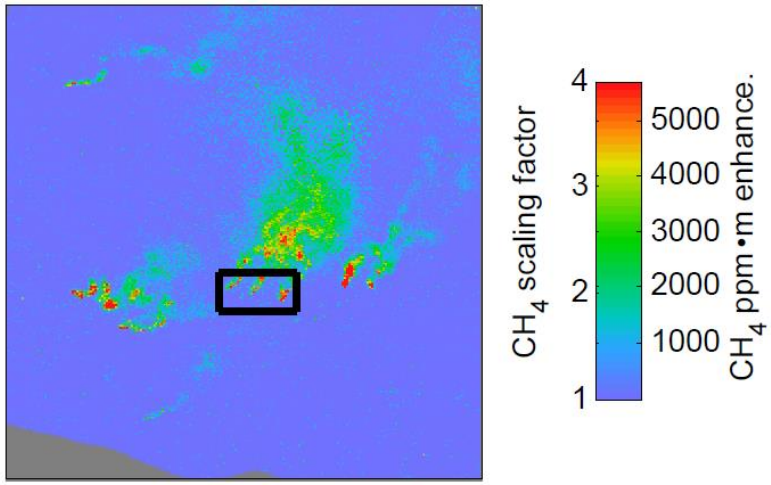
Results (CH_4)

- Example 1: Coal mine ventilation shaft emissions

(a) 20 April 2015, 18:06:24 UTC



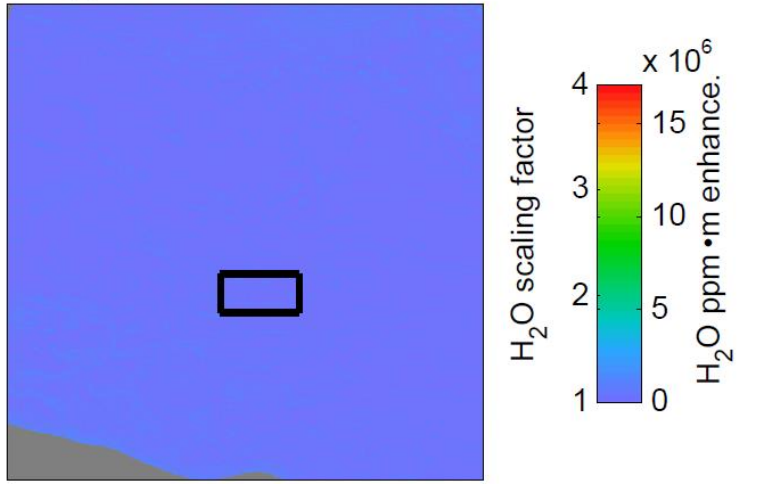
(b) CH_4: 20 April 2015, 18:06:24 UTC



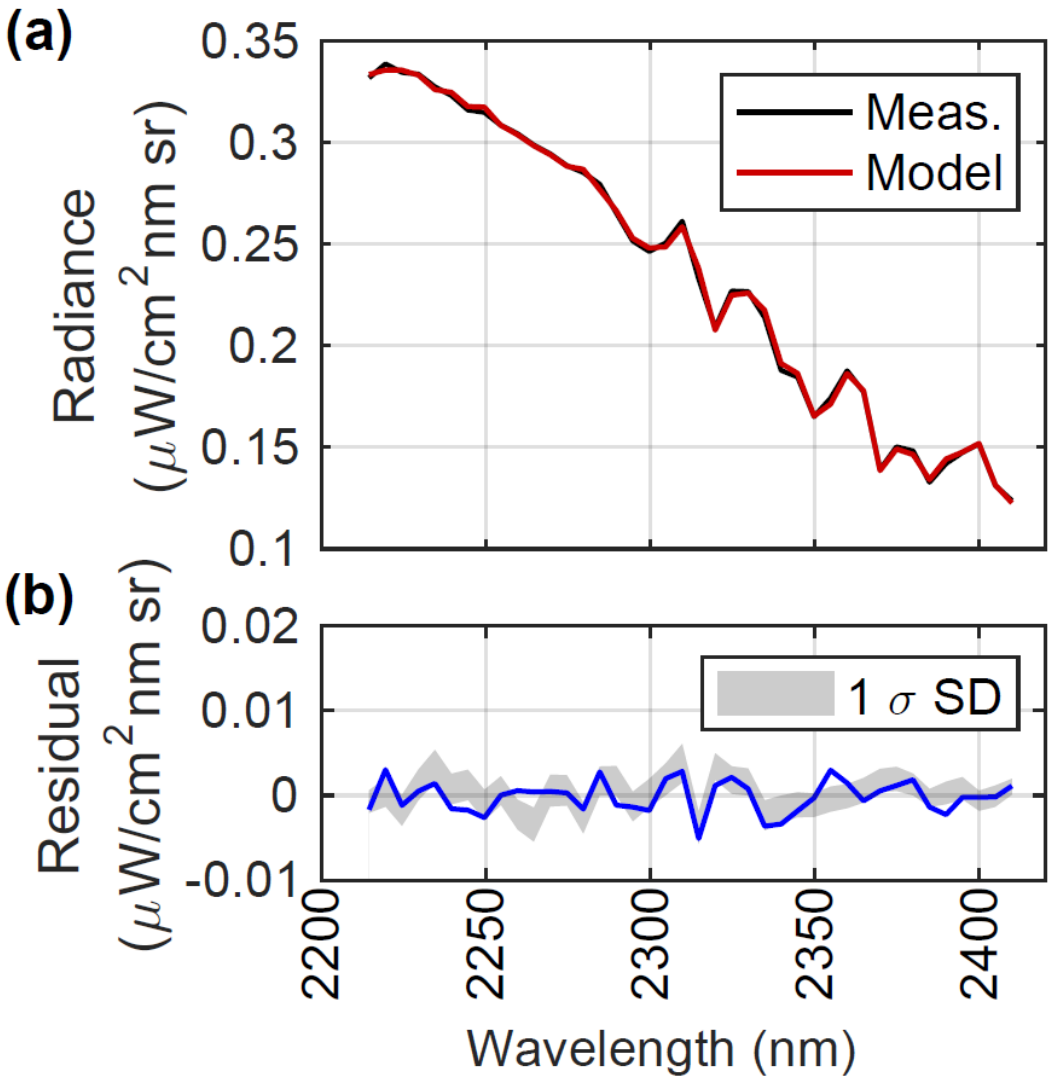
(c) 20 April 2015, 18:06:24 UTC

(d) Google Earth: 15 March 2015

(e) H_2O: 20 April 2015, 18:06:24 UTC



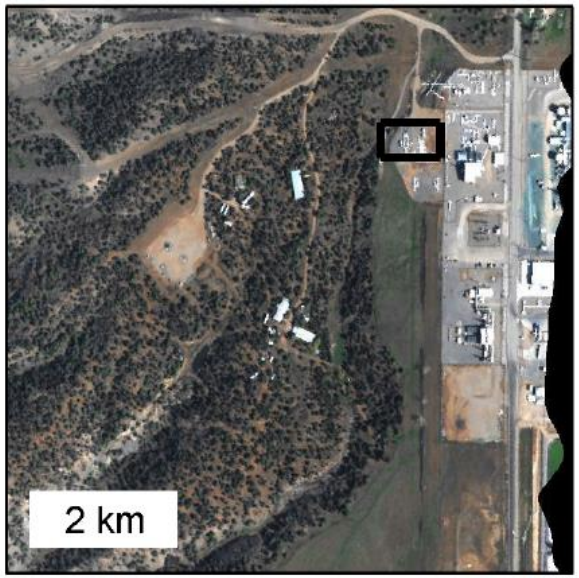
- Example 1: CH_4 retrieval radiance fits



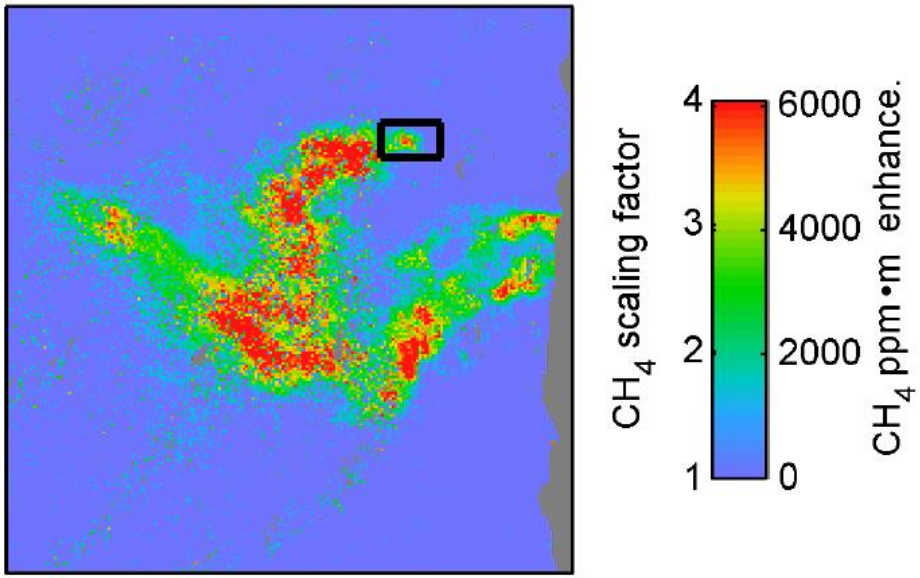
Results (CH_4)

- Example 2: Gas processing plant

(a) 20 April 2015, 16:07:19 UTC



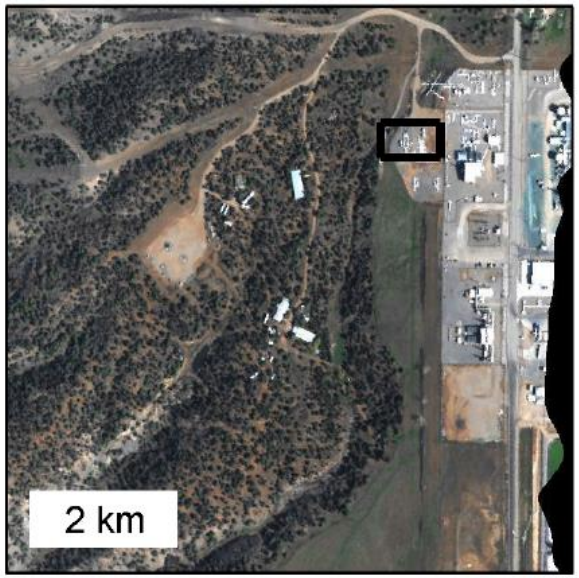
(b) CH_4: 20 April 2015, 16:07:19 UTC



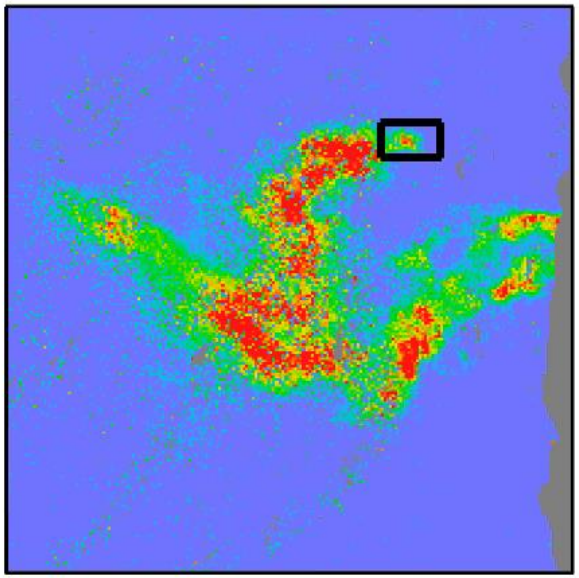
Results (CH_4)

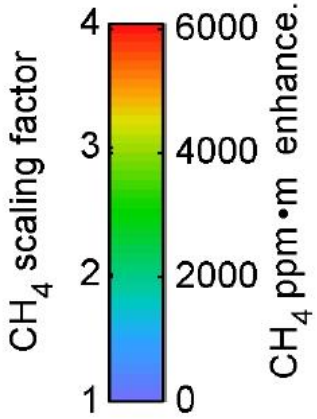
- Example 2: Gas processing plant

(a) 20 April 2015, 16:07:19 UTC



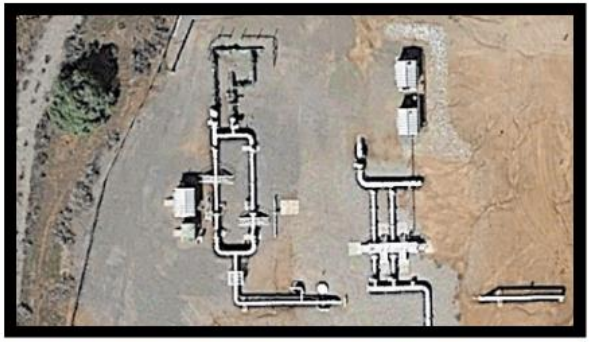
(b) CH_4: 20 April 2015, 16:07:19 UTC





(c) 20 April 2015, 16:07:19 UTC

(d) Google Earth: 16 March 2015

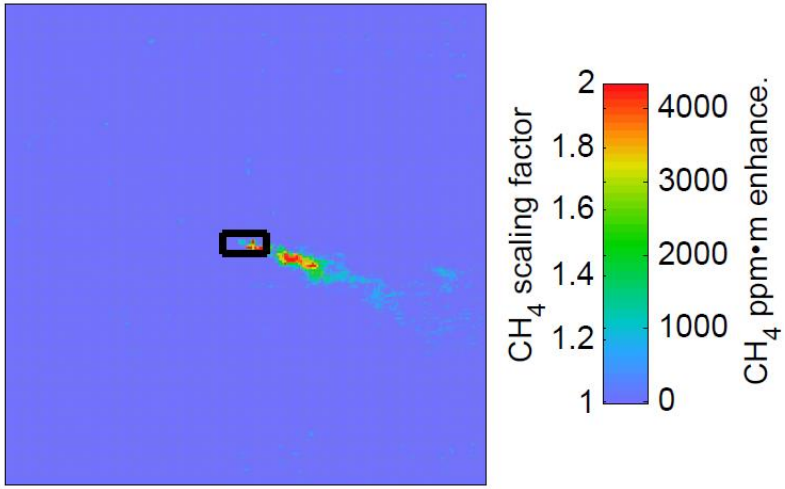


Results (CH_4)

- Example 3: Tank emissions

(a) 19 April 2015, 22:11:27 UTC

(b) CH_4: 19 April 2015, 22:11:27 UTC

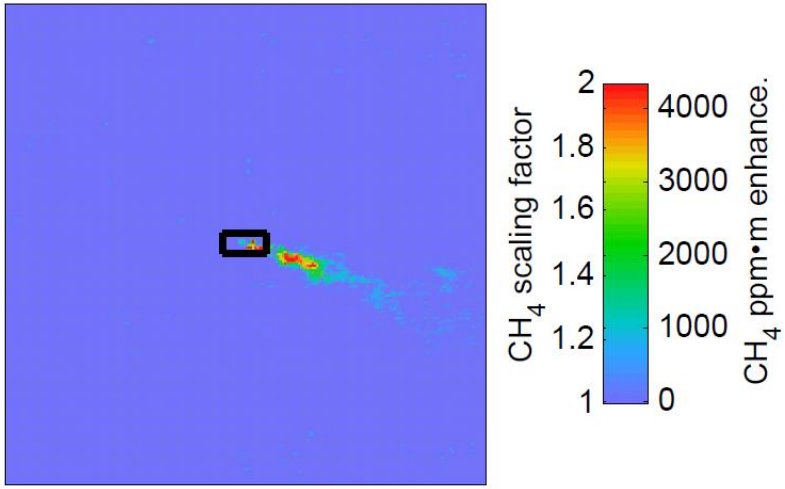


Results (CH_4)

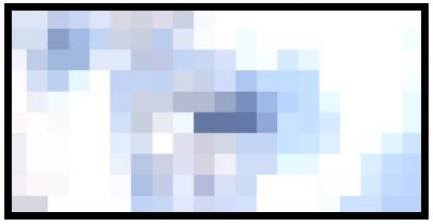
- Example 3: Tank emissions

(a) 19 April 2015, 22:11:27 UTC

(b) CH_4: 19 April 2015, 22:11:27 UTC



(c) 19 April 2015, 22:11:27 UTC

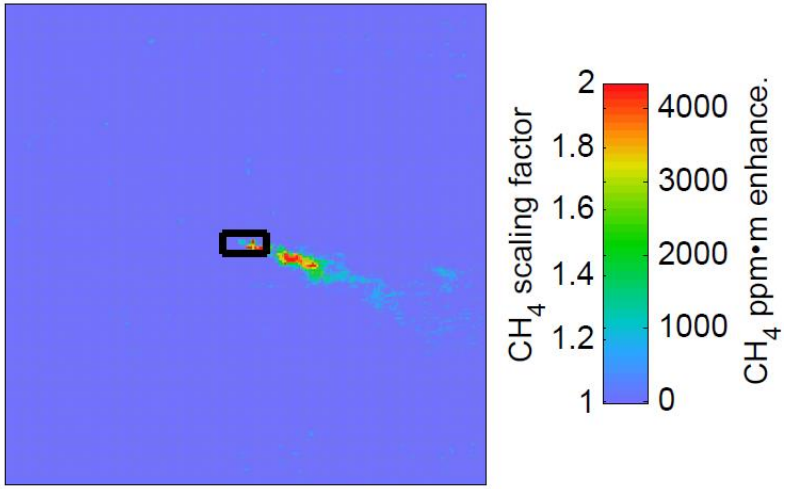


(d) Google Earth: 15 March 2015

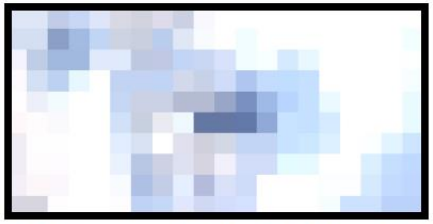
- Example 3: Tank emissions

(a) 19 April 2015, 22:11:27 UTC

(b) CH_4: 19 April 2015, 22:11:27 UTC

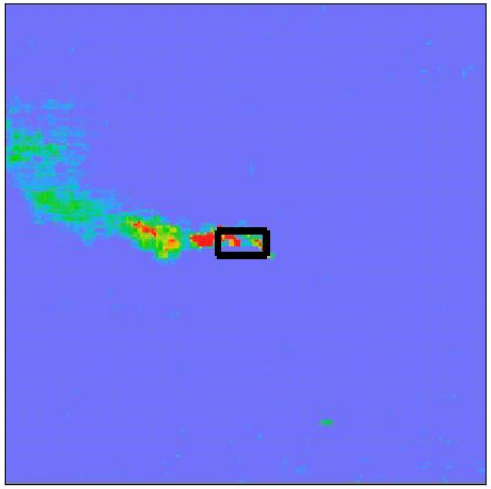


(c) 19 April 2015, 22:11:27 UTC



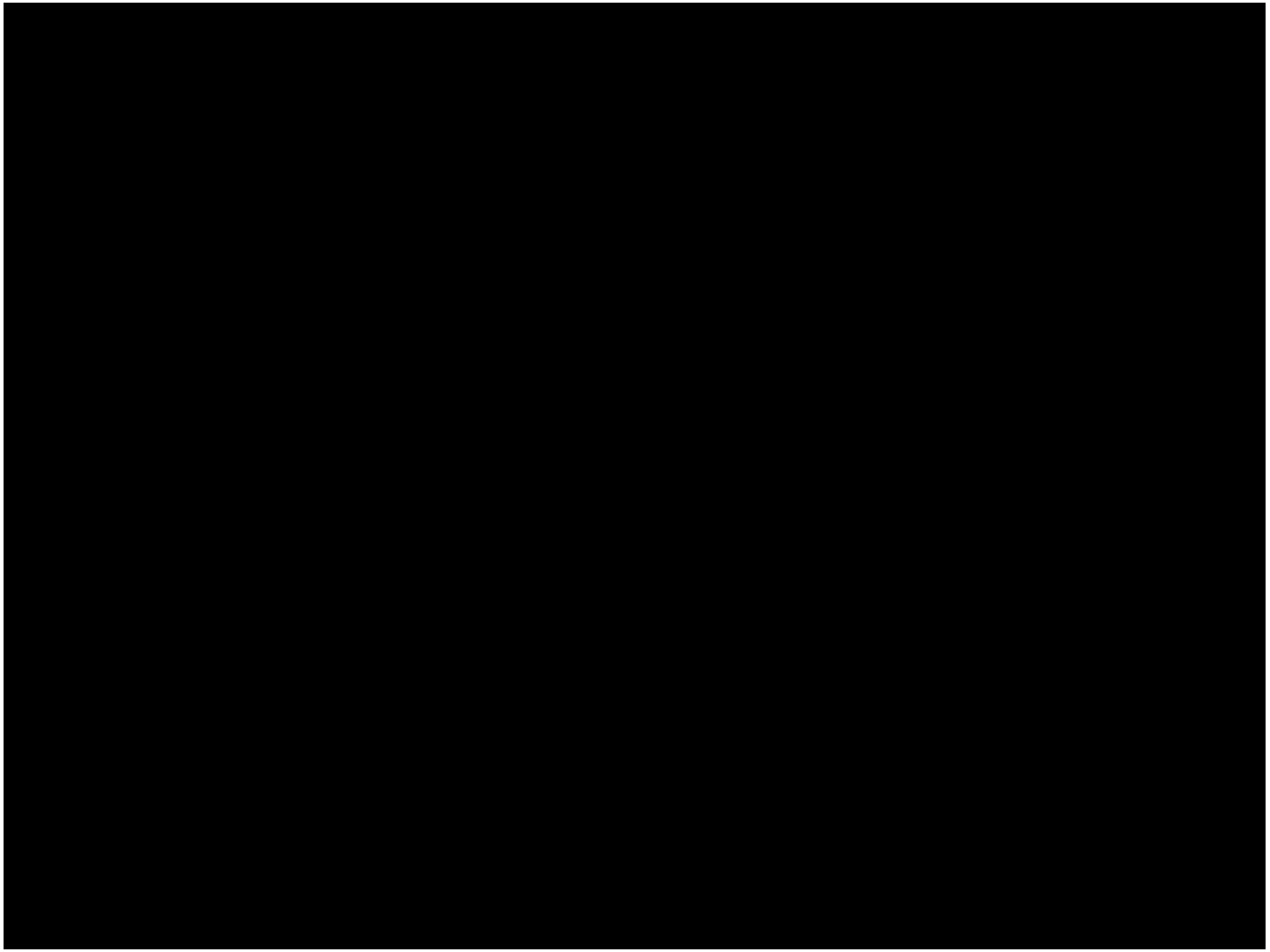
(d) Google Earth: 15 March 2015

(e) CH_4: 21 April 2015, 17:04:17 UTC



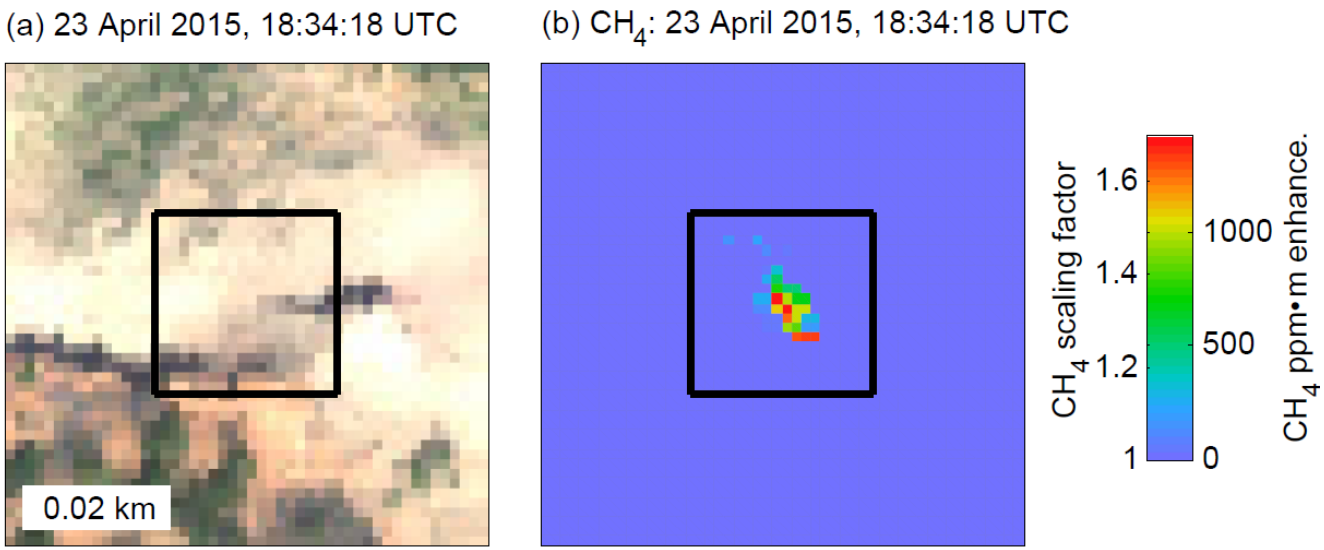
Results (CH_4)

- Example 3: Tank emissions (CH_4 thermal camera)



Results (CH_4)

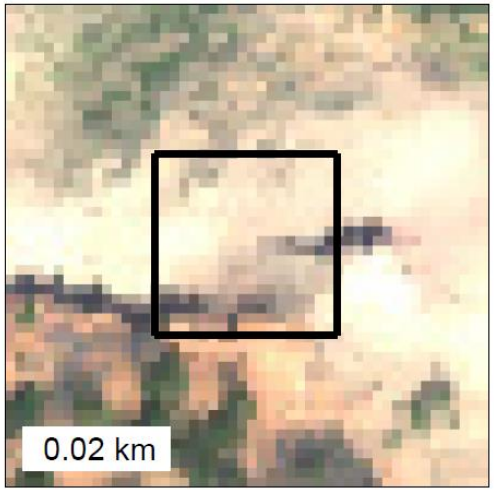
- Example 4: Natural source at “Moving Mountain”



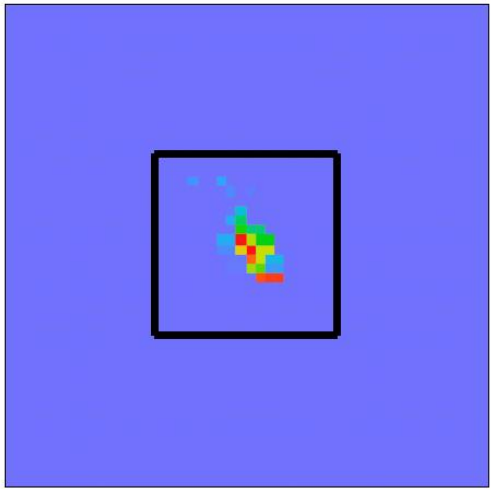
Results (CH_4)

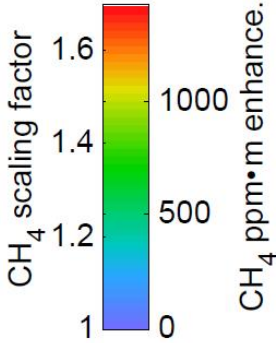
- Example 4: Natural source at “Moving Mountain”

(a) 23 April 2015, 18:34:18 UTC



(b) CH_4: 23 April 2015, 18:34:18 UTC





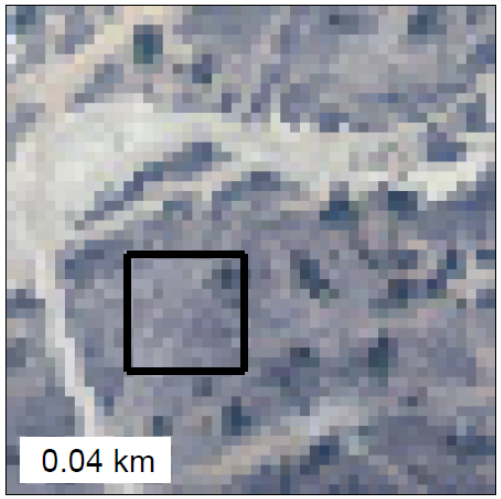
(c) 23 April 2015, 18:34:18 UTC

(d) Google Earth: 11 Aug. 2015

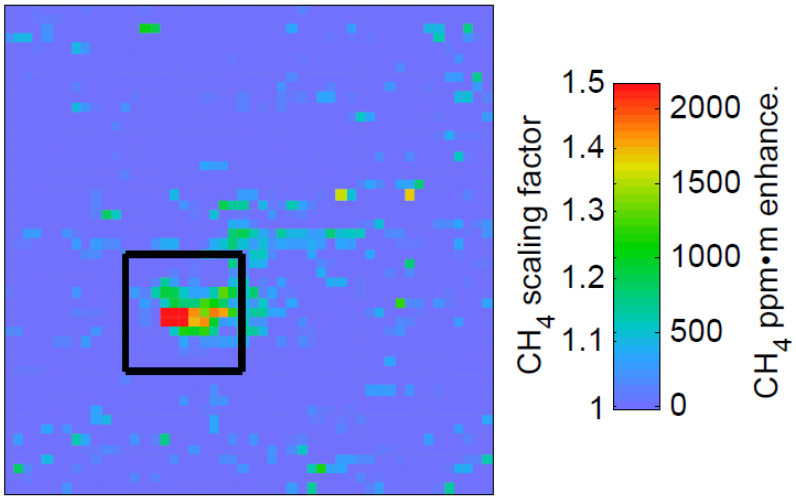
Results (CH_4)

- Example 5: Pipeline leak

(a) 19 April 2015, 18:35:12 UTC



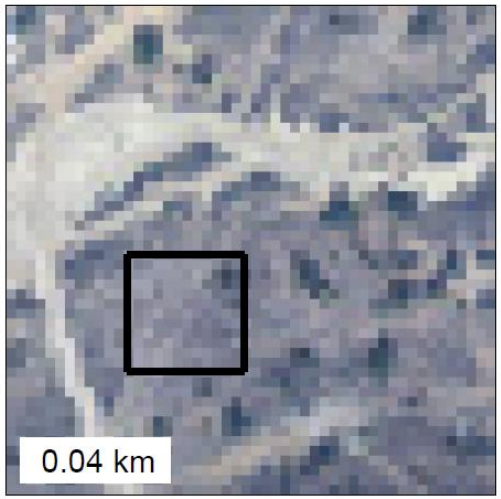
(b) CH_4: 19 April 2015, 18:35:12 UTC



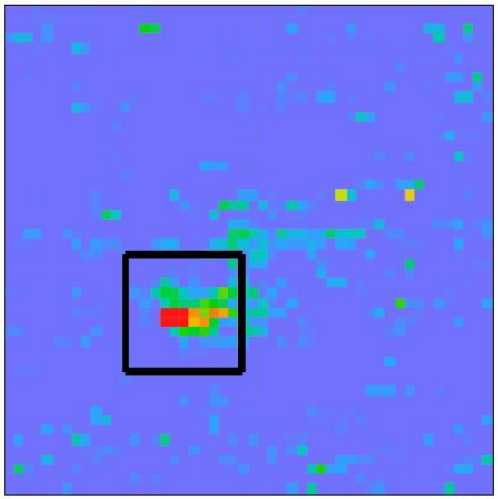
Results (CH_4)

- Example 5: Pipeline leak

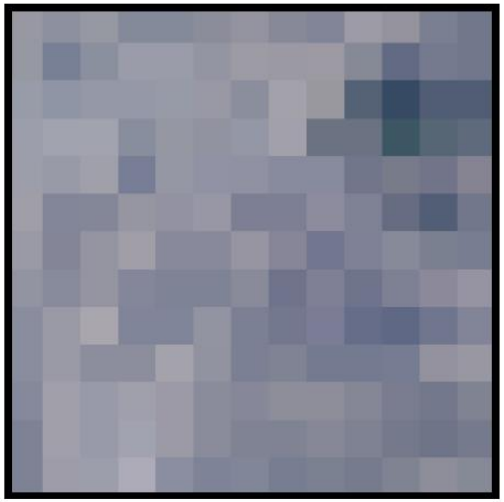
(a) 19 April 2015, 18:35:12 UTC



(b) CH_4: 19 April 2015, 18:35:12 UTC



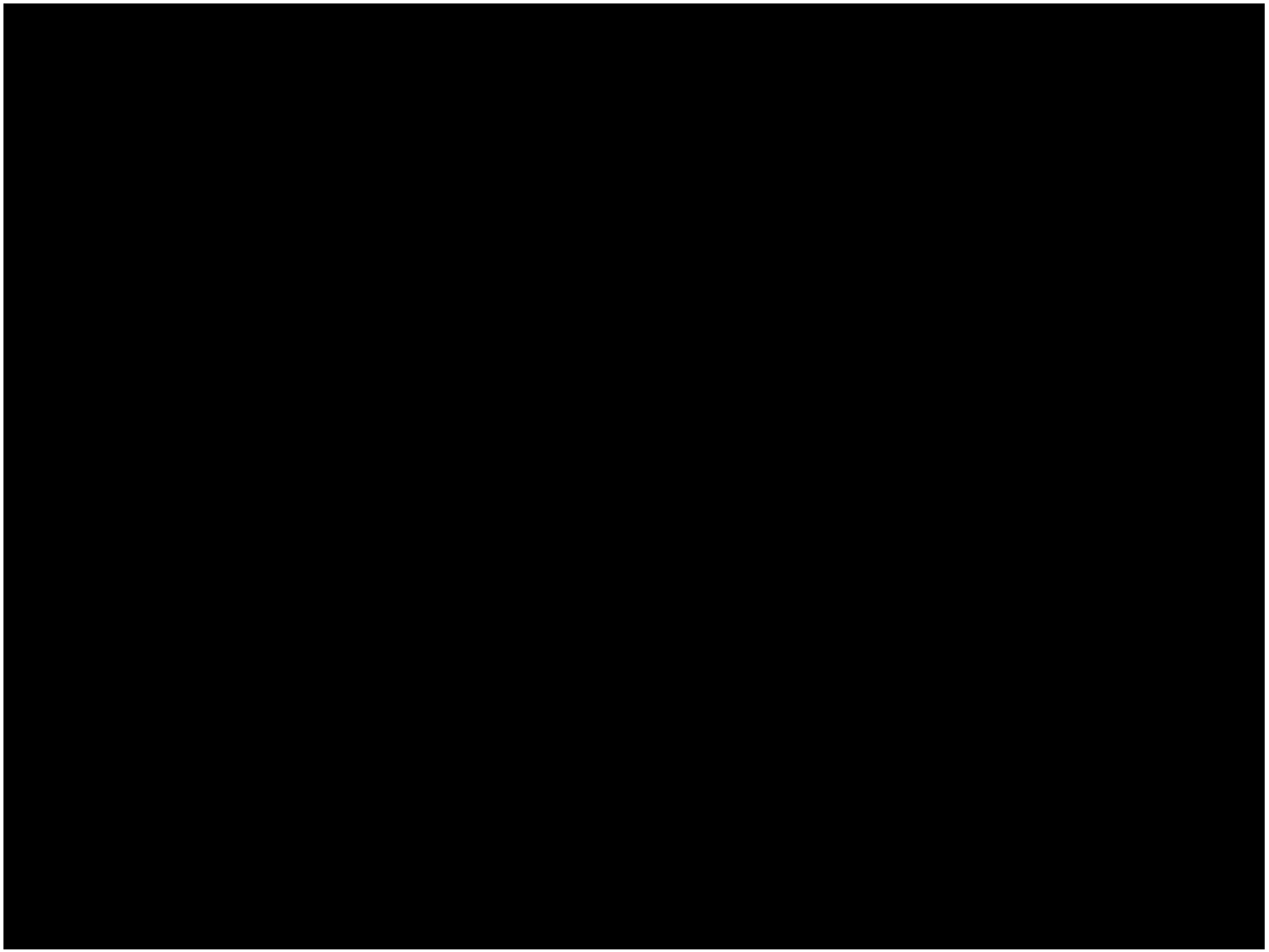
(c) 19 April 2015, 18:35:12 UTC



(d) Google Earth: 15 March 2015

Results (CH_4)

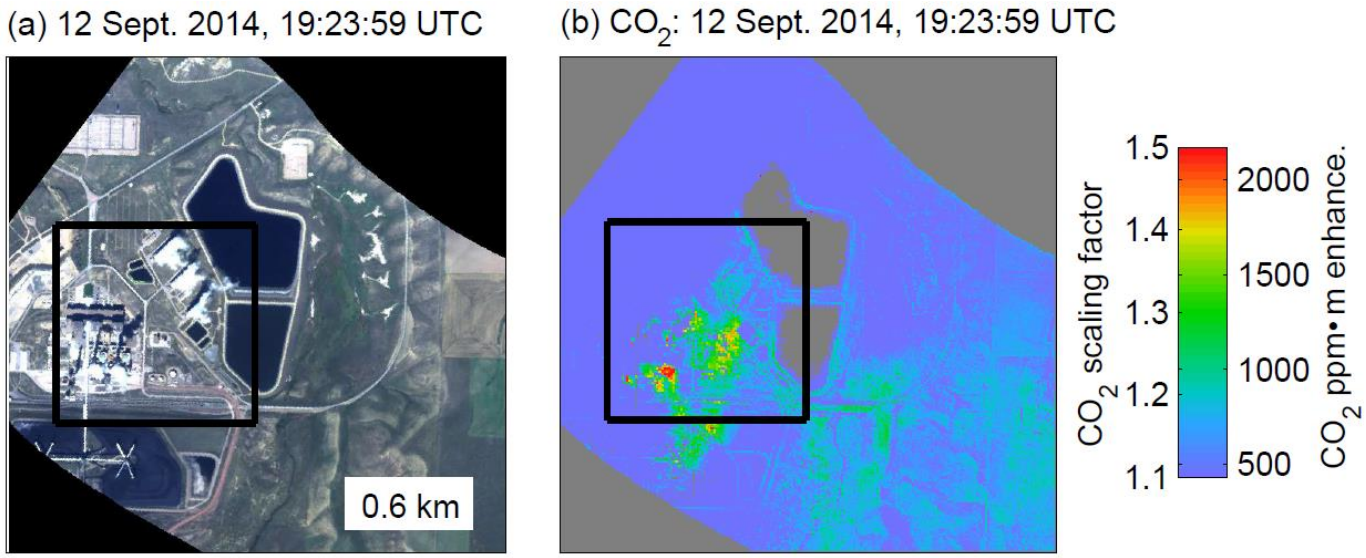
- Example 5: Pipeline leak (CH_4 thermal camera)



- Example 5: Operators shut down pipeline

Results (CO_2, H_2O)

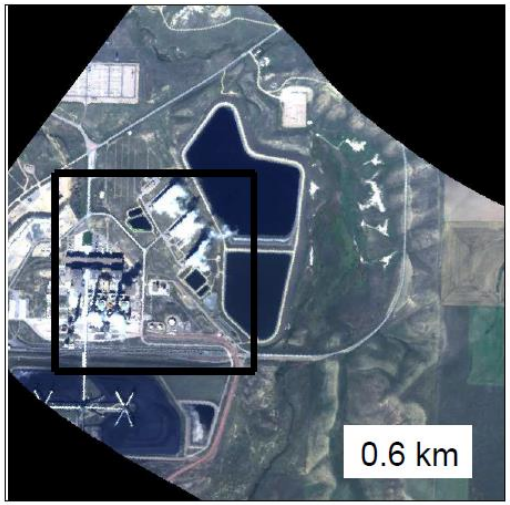
- Example 6: Power plant (2014 flight)



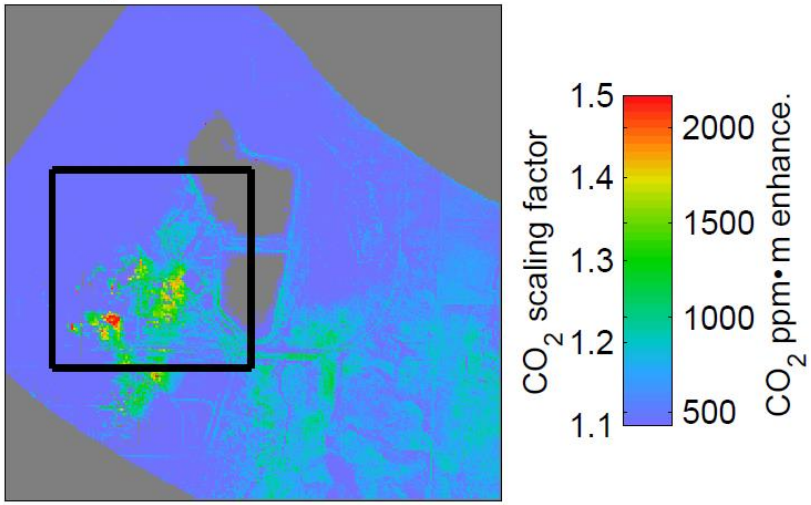
Results (CO_2, H_2O)

- Example 6: Power plant (2014 flight)

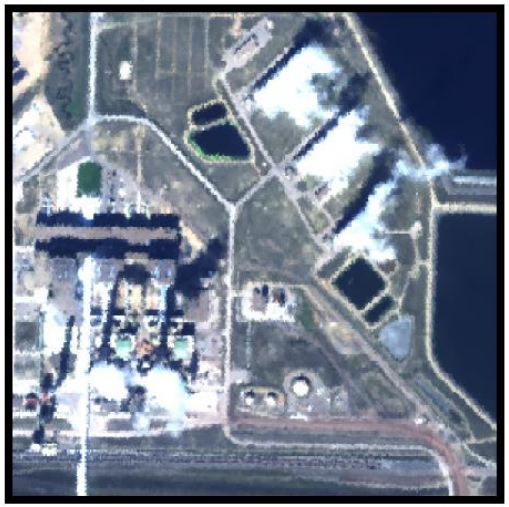
(a) 12 Sept. 2014, 19:23:59 UTC



(b) CO_2: 12 Sept. 2014, 19:23:59 UTC

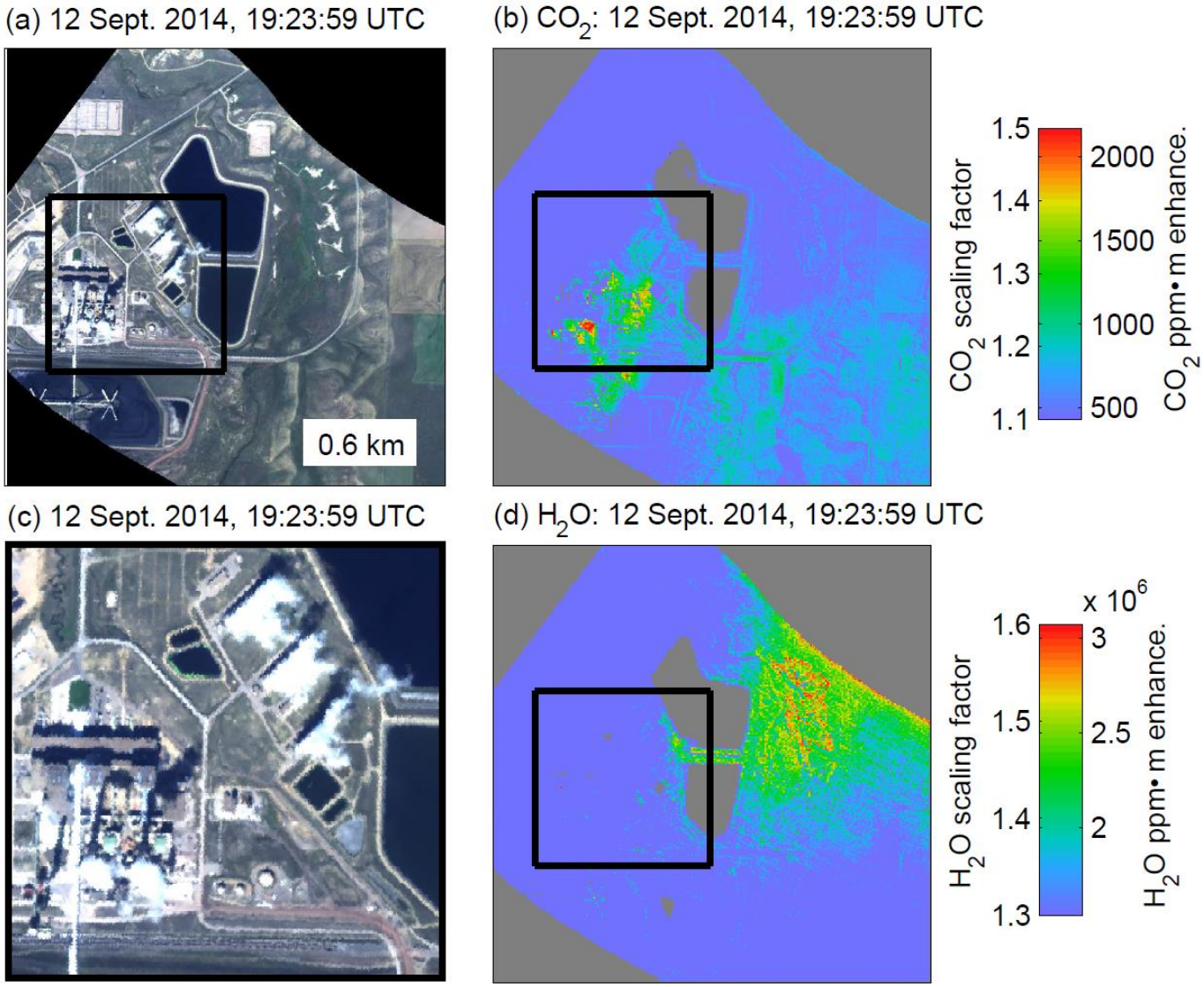


(c) 12 Sept. 2014, 19:23:59 UTC



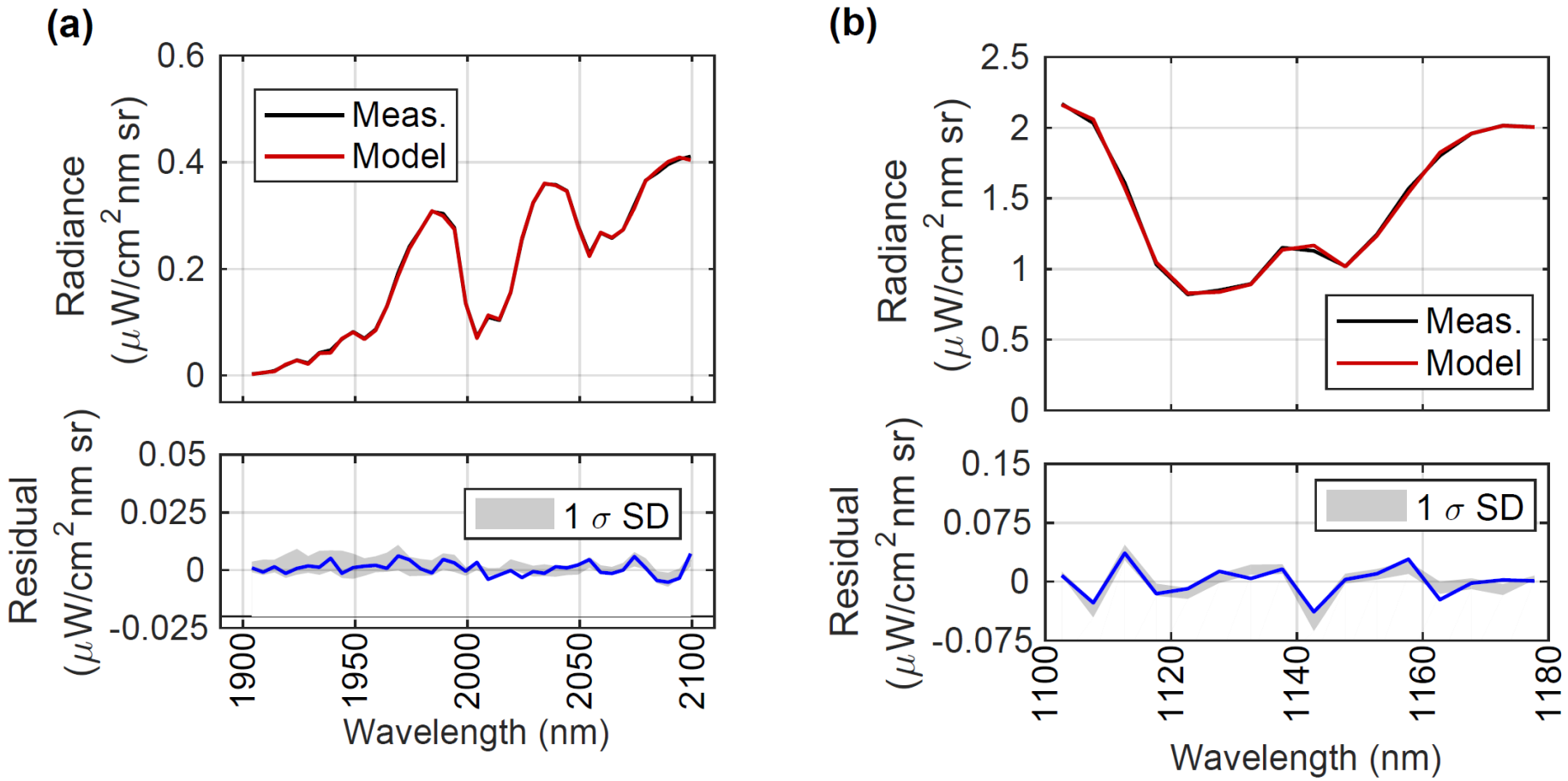
Results (CO_2, H_2O)

- Example 6: Power plant (2014 flight)

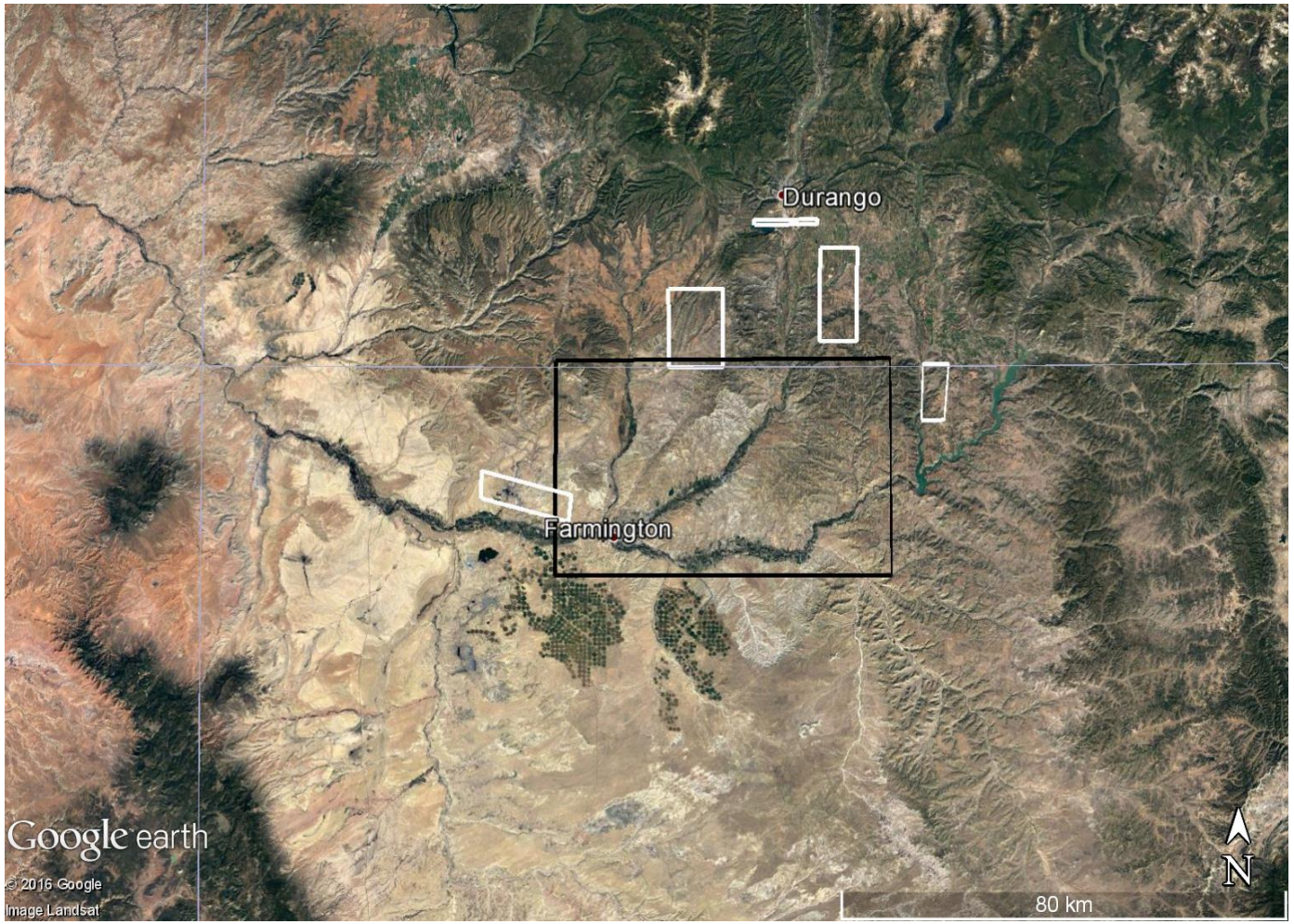


Results (CO_2, H_2O)

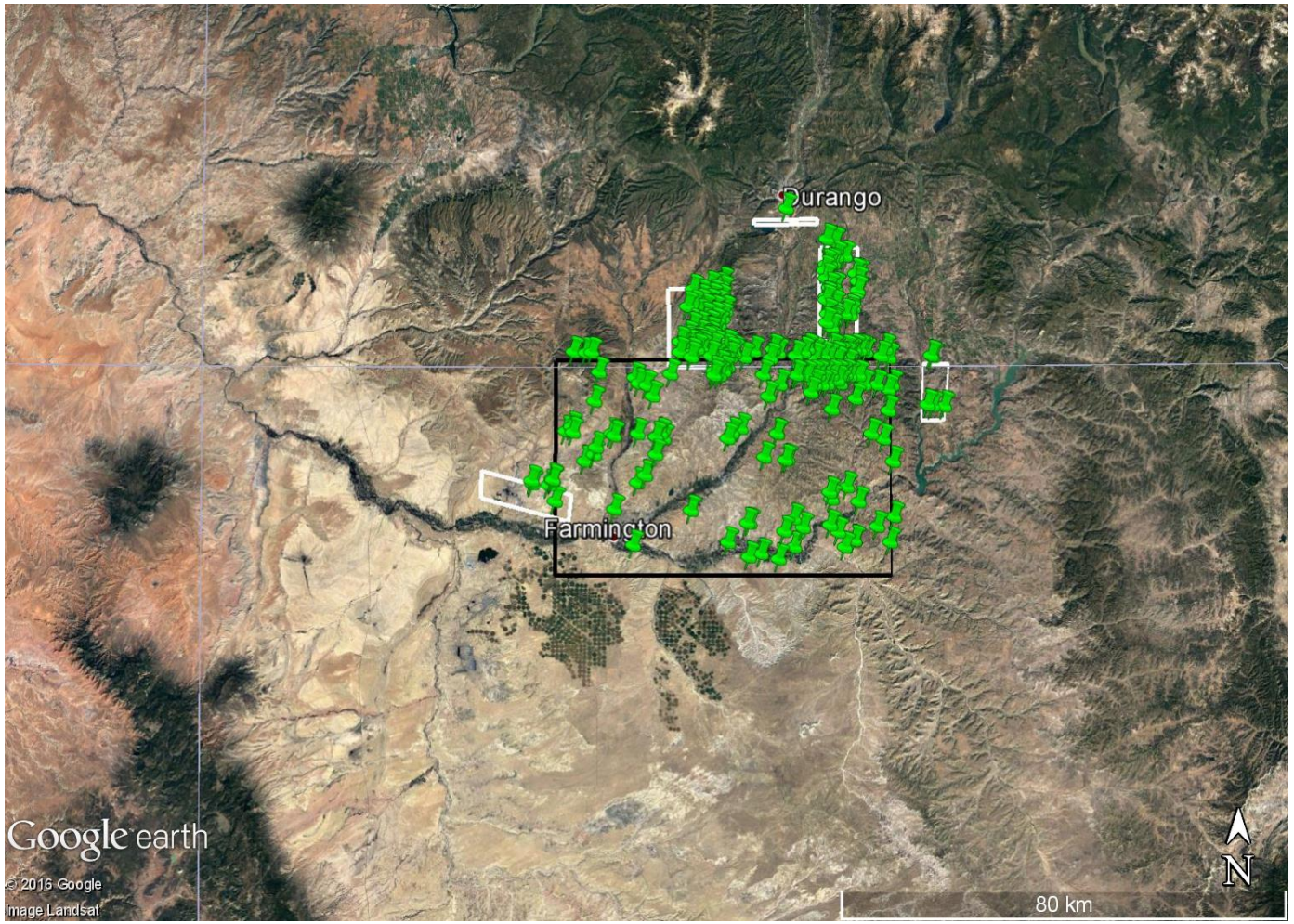
- Example 6: CO_2 and H_2O retrieval radiance fits



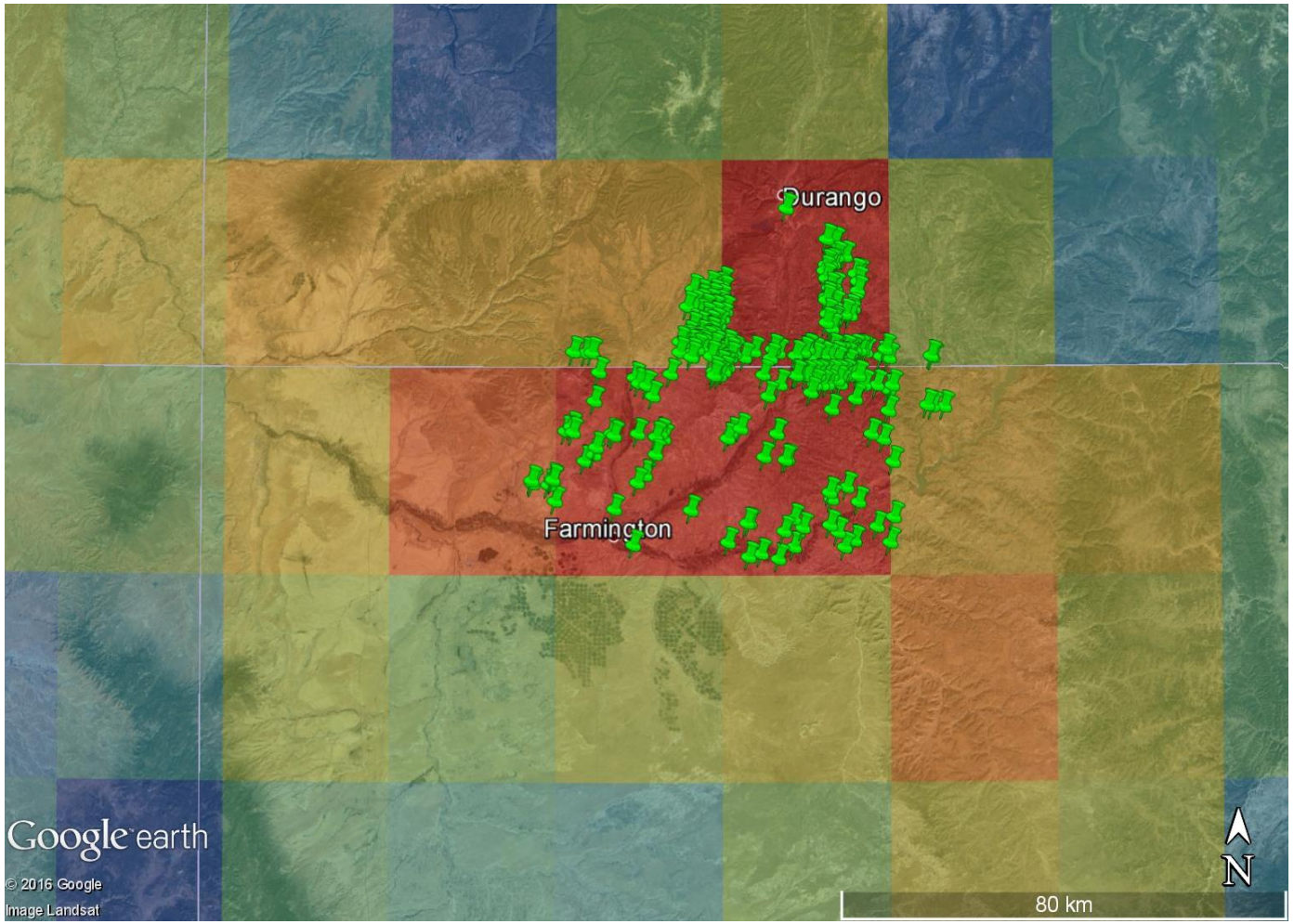
- Observed CH_4 plumes



- Observed CH_4 plumes (Frankenberg et al., 2016)



- Observed CH_4 plumes (Frankenberg et al., 2016)



- Source categories

Total flight hours	Total ground coverage (km^2)	Source category	Specific source	Number of plumes	Percentage of total
9.2	2,530.8	Natural gas production	Possible well completions	10	3.9%
			Wellpad insfrastructure	135	52.5%
			Tanks	64	24.9%
			Gas processing plants	7	2.7%
			Unknown facility	15	5.8%
			Unknown infrastructure	2	0.8%
		Natural gas transmission	Buried natural gas pipeline leaks	3	1.2%
		Coal mining	Mine ventilation shaft	1	0.4%
		Geological (terrestrial)	Coal bed CH_4 seeps	2	0.8%
		Unknown		18	7.0%
		Total		257	100.0%

Conclusions

- AVIRIS-NG permits quantitative mapping of CH_4, CO_2, and H_2O emissions
- Offers the potential to:
  - Map large areas rapidly
  - Identify unknown emission sources (i.e. natural gas pipeline leaks)
  - Better understand partitioning of anthropogenic and natural emission sources

Acknowledgments

- JPL:
  - AVIRIS/AVIRIS-NG team
  - Simon Hook and Bill Johnson (thermal camera)

- NASA:
  - Jack Kaye (Four Corners campaign)

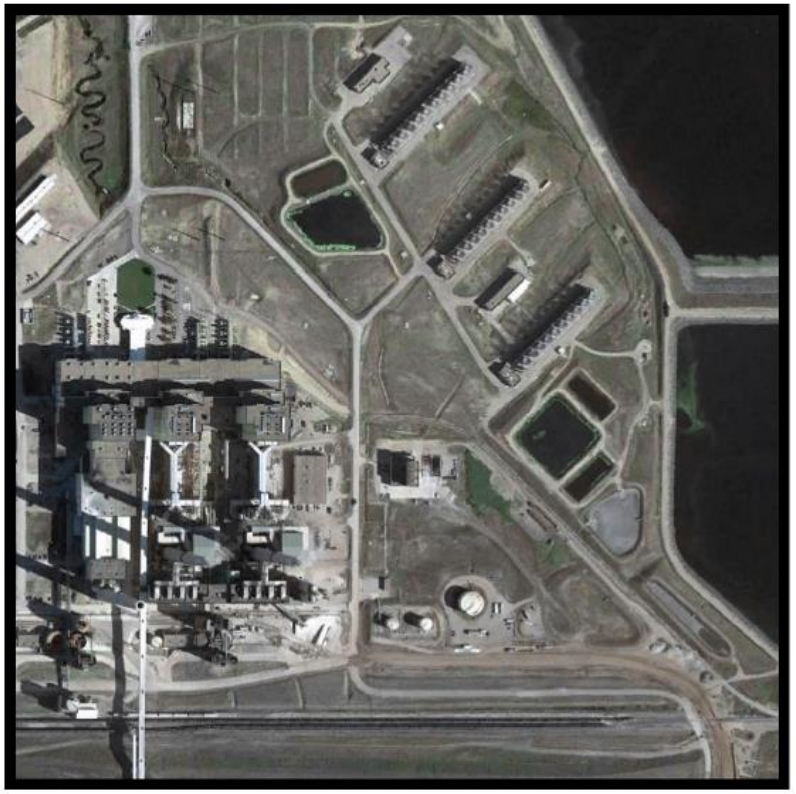
NASA

Results (CO_2, H_2O)

- Example 6: Power plant (2014 flight)

(a) 12 Sept. 2014, 19:23:59 UTC

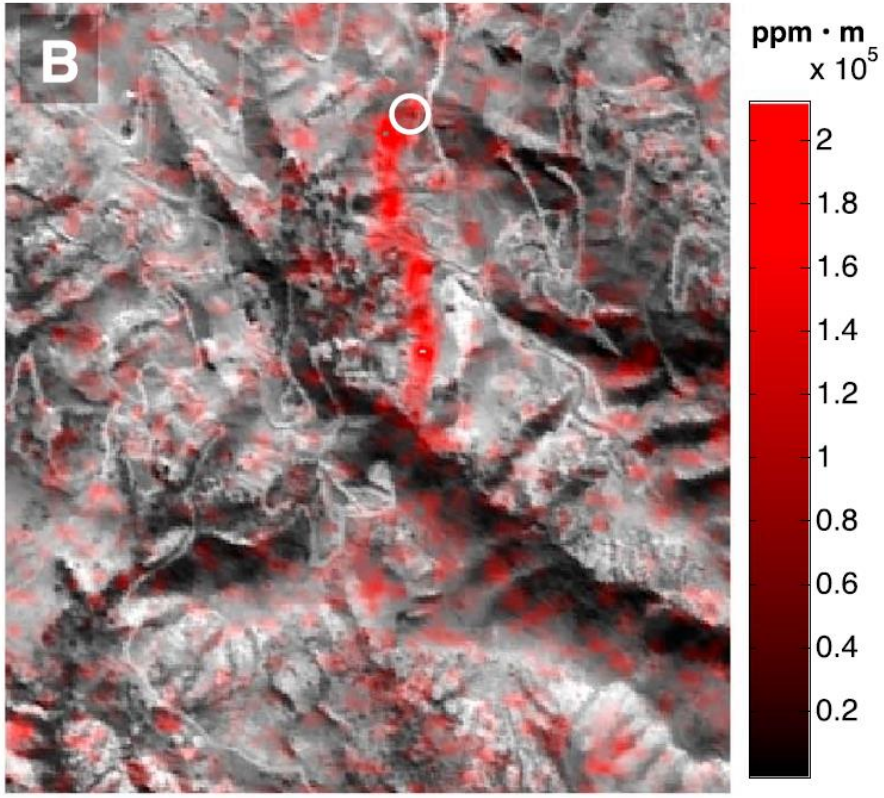
(b) Google Earth: 2 Sept. 2014



Results (Aliso Canyon)

- Orbital Hyperion instrument and AVIRIS also observed CH_4 plume (Thompson et al., 2016)

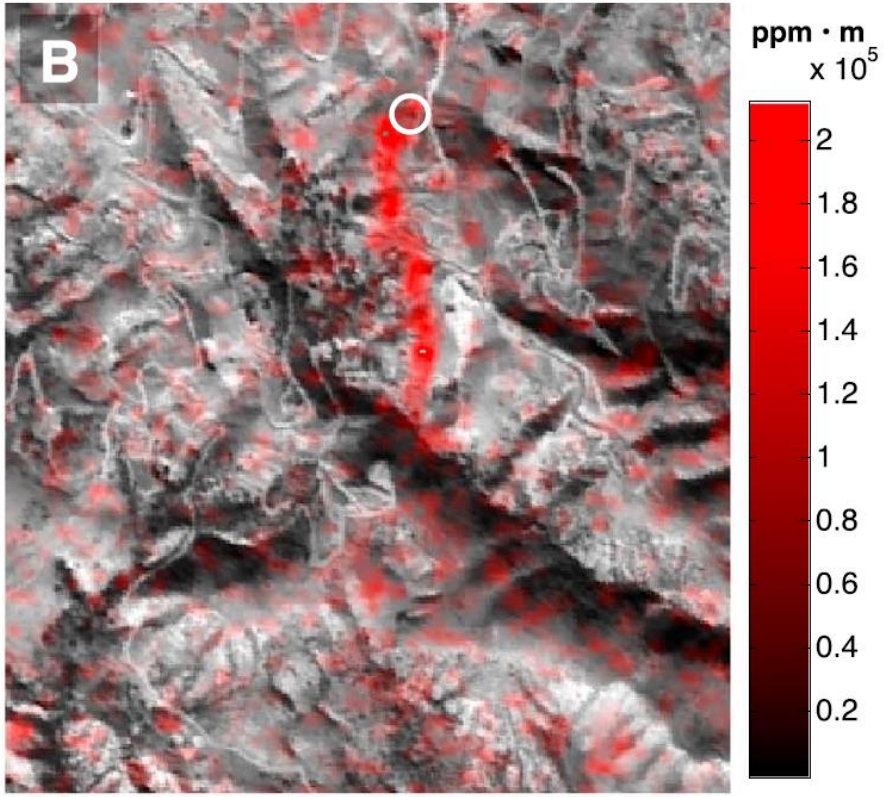
Hyperion (10 nm): 1/1/16, 16:39 UTC
Low Earth orbit



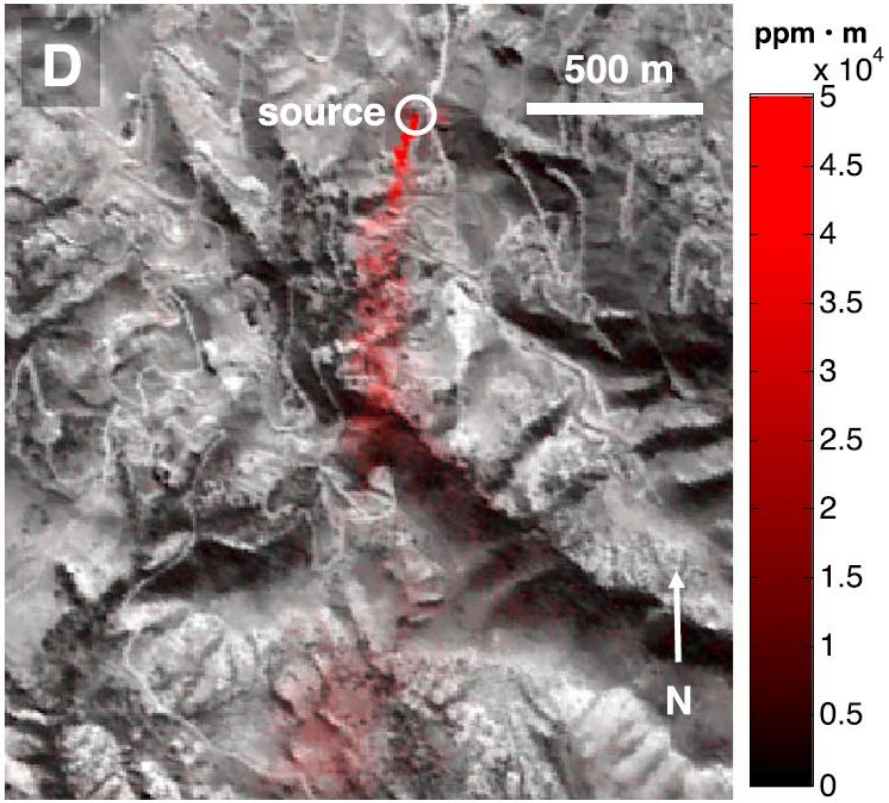
Results (Aliso Canyon)

- Orbital Hyperion instrument and AVIRIS also observed CH_4 plume (Thompson et al., 2016)

Hyperion (10 nm): 1/1/16, 16:39 UTC
Low Earth orbit

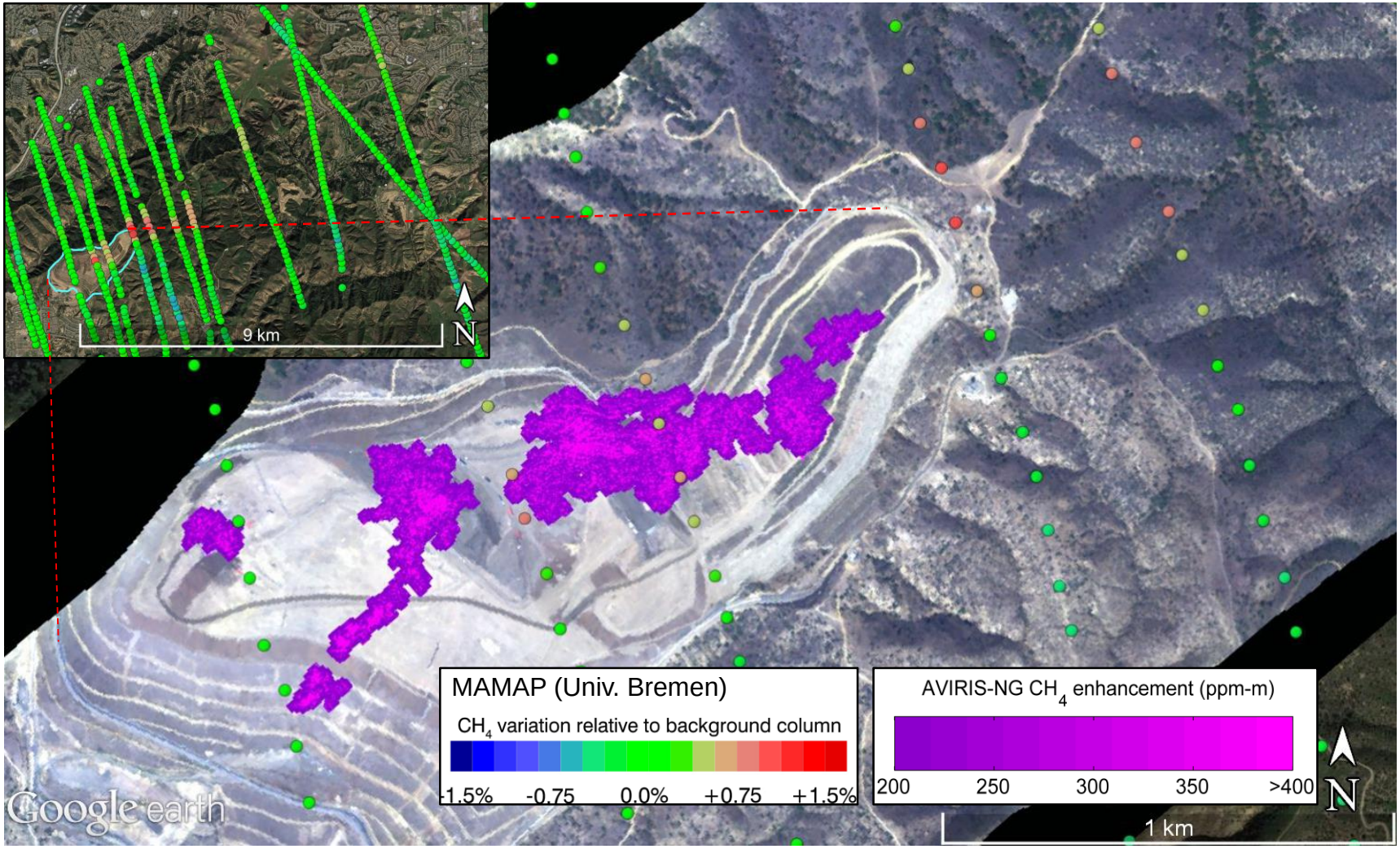


AVIRIS (10 nm): 1/12/16, 20:25 UTC
6.6 km above ground level



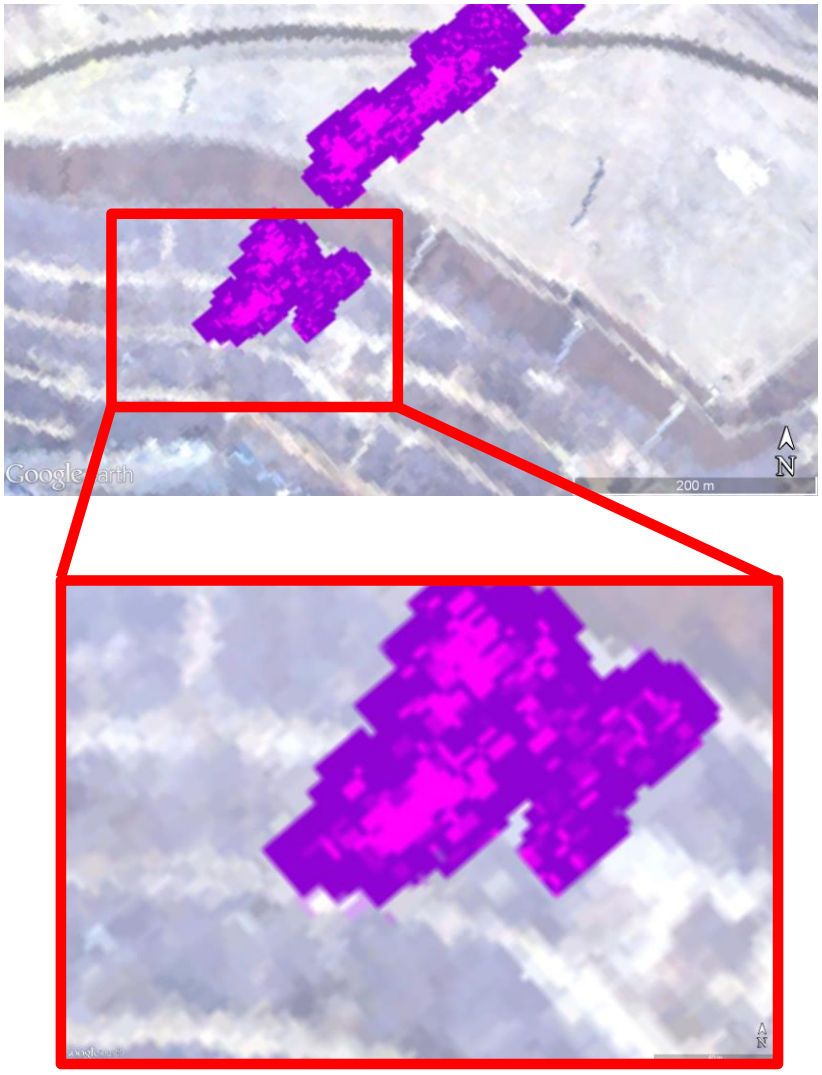
Results (Olinda Alpha Landfill)

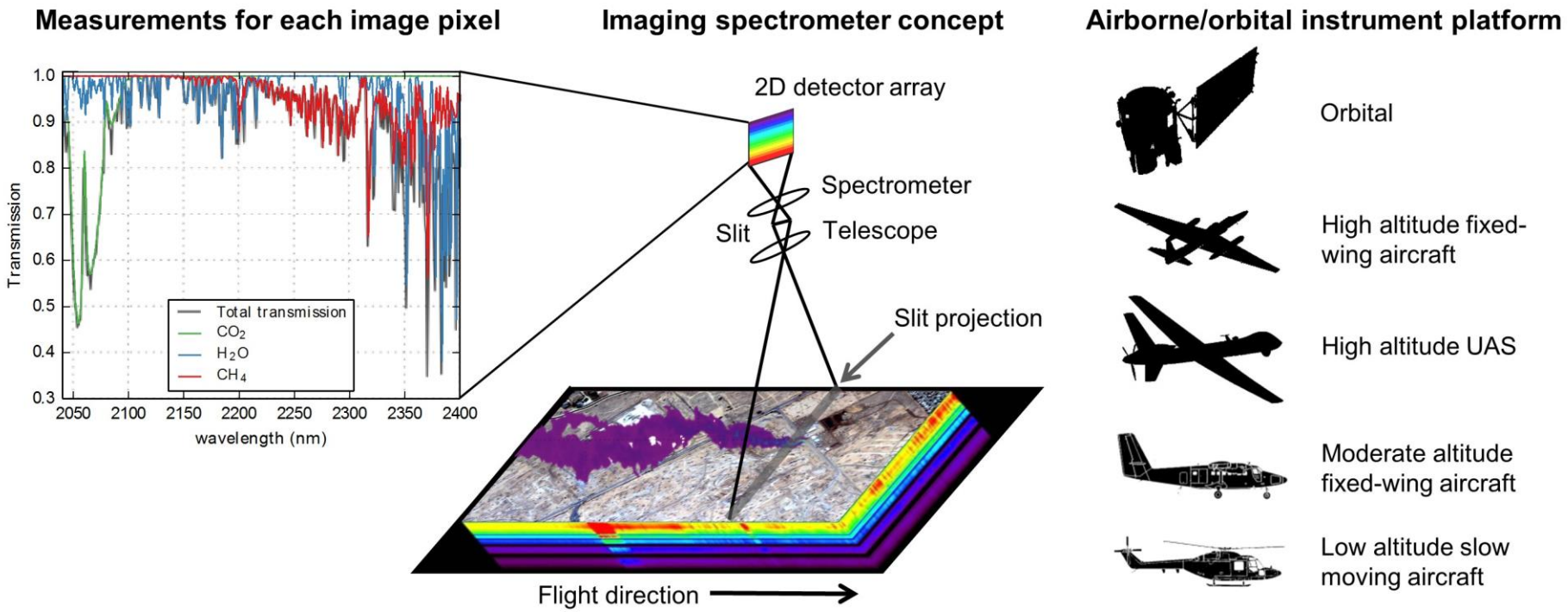
- CH_4 from Olinda Alpha Landfill (Krautwurst et al., 2017)



Results (Olinda Alpha Landfill)

- CH_4 from Olinda Alpha Landfill



Future instrument design

- 1 nm spectral resolution for improved gas sensitivity
- Quantitative mapping of CH_4, CO_2, H_2O, CO, N_2O
- NRC RFI #2: Understanding anthropogenic methane and carbon dioxide point source emissions (Duren et al., 2016)